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NATURAL CROSSING AND SEGREGATION IN SERICEA LESPEDEZA, *LESPEDEZA CUNEATA* (DUMONT) G. DON[1]

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GENERAL observations (3),[3] and in some cases experimental data, have shown that a number of legumes are self-pollinated and rarely if ever cross-fertilized. Several species of lespedeza have flowers of two kinds (2). One type of flower has a fully developed corolla and is conspicuous. In the other, the corolla is rudimentary, and the flower does not open until the developing pod forces the calyx apart. In Korean lespedeza, *Lespedeza stipulacea* Maxim., the pollen germinates within the anther sacs (1) and the pollen tubes enter the stigma after penetrating the anther wall. Pollination in *L. cuneata* (Dumont) G. Don., probably follows a similar pattern. Seed pods from the petaliferous and apetalous flowers can be identified (2). As the apetalous flowers are cleistogamous it is possible to use this character as evidence of self-pollination. The normal growth of most strains of sericea lespedeza tends to be more or less erect. Among several hundred individual plants grown at Statesville, N. C., one was found that was procumbent.

These studies on hybridization have been concerned with the progeny of the procumbent plant of sericea lespedeza which appeared among the seedlings of seed lot F. P. I. 65903. This lot of seed was an original introduction from Japan. Selfed seeds were from apetalous flowers and identified by the shape of the pod and style. Seeds from petaliferous flowers were considered to be open-pollinated and thus subject to either cross- or self-pollination. In recording habit of growth, plants with main stems in a horizontal position were considered to be procumbent (Fig. 1). All other plants were recorded as assurgent and were classified in four categories, (a) erect, (b) semi-

[1]Cooperative investigations by the Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. D. A., and the North Carolina Department of Agriculture and the North Carolina Agricultural Experiment Station at Statesville, N. C. Published with the approval of the Director of the North Carolina Agricultural Experiment Station as Paper No. 213 of the Journal Series. Received for publication June 15, 1945.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 5.

erect with stems nearly erect, (c) medium with majority of stems reclining at a 45° angle, and (d) semiprocumbent with some stems procumbent and others reclining at an angle of more than 45°.

NATURAL CROSSING

The original procumbent plant was surrounded by several hundred assurgent plants so that there was a good opportunity for cross-pollination. Seed obtained from the procumbent plant in 1937 was planted in the greenhouse and the seedlings set out in the field. Petaliferous flowers were observed to be abundant on the procumbent plant in 1937; however, no record was made regarding the number present in the seed planted in the greenhouse. Out of a total of 97 plants set in the field, 14.6%, as previously reported (4), developed into assurgent plants (Fig. 2).

Seed was gathered from the original procumbent plant again in 1938, and 180 seedlings from selfed seed were set in the field. All of these seedlings proved to be procumbent, thus indicating that the original procumbent plant was not segregating.

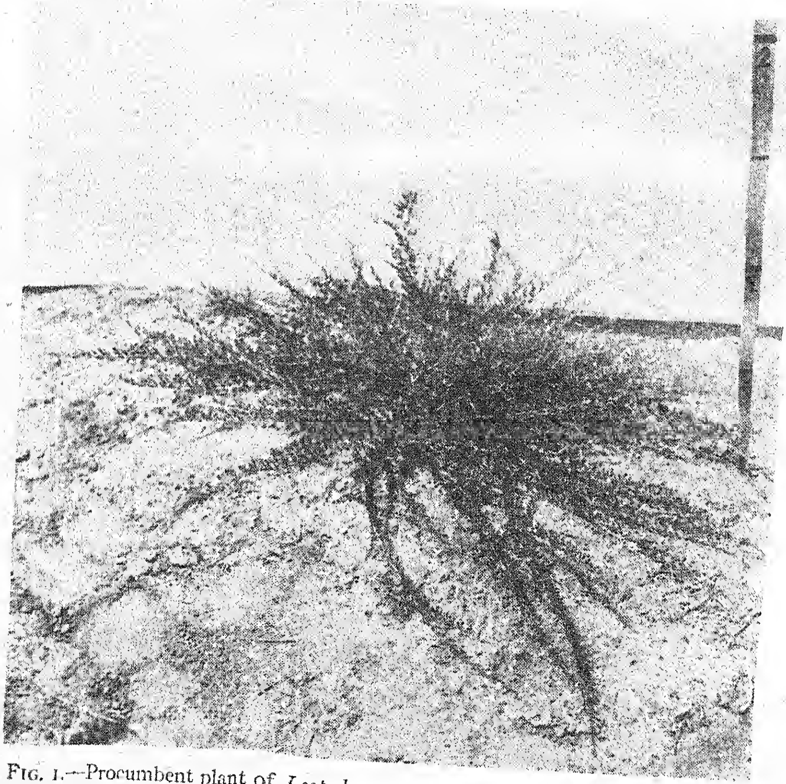

FIG. 1.—Procumbent plant of *Lespedeza cuneata* from seed lot F.P.I. 65903. This plant was the source of seed of the F_1 plants shown in Fig. 2.

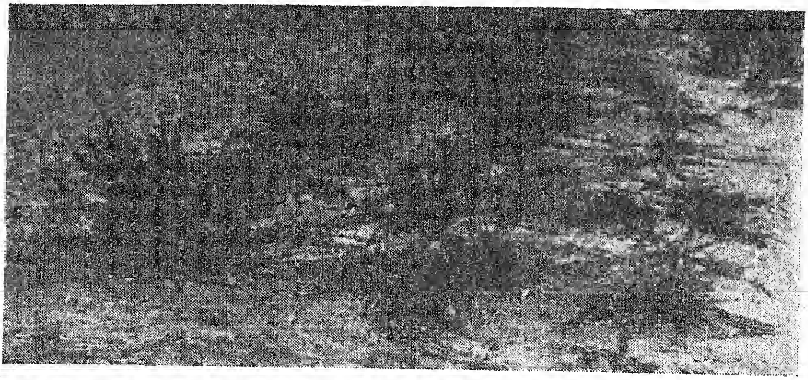

FIG. 2.—Assurgent and procumbent F_1 progeny of the procumbent mother plant shown in Fig. 1.

The progeny of 15 first and 7 second generation procumbent plants were observed for off-type plants, each generation being from selfed seed. The results as given in Table 1 indicate either a small

TABLE 1.—*Number of assurgent and procumbent plants in the F_1 and F_2 progeny of self-pollinated procumbent plants of Lespedeza cuneata.*

Line	Assurgent	Procumbent	Total
One Generation of Known Selfing			
281	1	54	55
285	1	9	10
286	–	3	3
287	–	17	17
288	–	7	7
289	–	14	14
290	–	3	3
293	–	14	14
294	–	52	52
159–226	1	129	130
305	1	31	32
308	–	91	91
312	–	34	34
314	1	14	15
161	–	8	8
Total............	5	480	485
Two Generations of Known Selfing			
164–232	2	160	162
165–234	2	154	156
166	–	8	8
167–236	1	108	109
168	–	57	57
171–239	1	139	140
172	–	66	66
Total............	6	692	698
Grand total.......	11	1,172	1,183

amount of segregation or an error. It is most likely that errors were made in selecting the apetalous seed. Among the 1,183 seedlings grown, 11 were assurgent. Whether this variation, amounting to 0.9% was due to errors in selection or to segregation, it would have little effect on the figures for the amount of natural crossing.

Seed from petaliferous flowers were obtained from five of the first generation procumbent plants. The F_1 progeny of the open-pollinated procumbent plants are classified as to habit of growth in Table 2. The natural crossing varied from 61.4 to 80.9%, with an average of 70.4%.

TABLE 2.—*Number of assurgent and procumbent plants in the F_1 progeny and percentage of natural crossing of open-pollinated procumbent plants of Lespedeza cuneata.*

Line	Assurgent				Pro-cumbent	Total No. of plants	Natural crossing %
	Erect	Semi-erect	Me-dium	Semipro-cumbent			
227	1	11	17	13	24	66	63.6
233	—	4	52	16	17	89	80.9
235	—	—	58	6	22	86	74.4
237	—	3	33	7	27	70	61.4
238	—	1	27	12	20	60	66.7
Total...	1	19	187	54	110	371	70.4

Vaseline slides placed under and in blooming plants of *L. cuneata* have failed to collect pollen when left for periods of 12 to 24 hours. Bees are usually abundant among the flowers and probably bring about cross-pollination.

SEGREGATION IN F_2 LINES

Selfed seed were obtained from 14 of the assurgent F_1 plants (Fig. 2). All of these F_1 plants were more or less intermediate between erect and procumbent, closely approaching the medium and semi-erect types. Data from the 521 F_2 plants are presented in Table 3. In three lines a range of plants from erect to procumbent was recovered. In most of the others, the range was from semi-erect to procumbent. In one line all the plants were either semiprocumbent or procumbent. These variations in the F_2 plants further support the F_1 data on natural crossing. Indications are that the inheritance of habit of growth is rather complex. As the source of pollen for the crosses is not known and F_3 data are not available, it would be only speculative to present a hypothesis relative to the mode of inheritance of habit of growth. The variation among the F_2 lines suggests that the pollen for the natural crosses may have been from several different sources as the female parents have been shown to be homozygous. Further knowledge of the effects of different pollen sources is needed.

Cursory observation did not reveal any variation in size or vigor between the mother plant and selfed or open-pollinated generations.

TABLE 3.—*Segregation of assurgent and procumbent plants in the F_2 of natural crosses of Lespedeza cuneata.*

Line	Assurgent				Procumbent	Total No. of plants
	Erect	Semi-erect	Medium	Semiprocumbent		
169–229	6	35	54	22	4	121
160–307	1	1	15	3	1	21
282	—	4	27	12	29	72
291	—	2	2	3	1	8
292	—	8	14	1	2	25
295	—	—	—	9	43	52
296	—	3	4	3	7	17
301	—	2	11	2	3	18
303	—	1	7	—	—	8
304	—	—	8	2	1	11
310	5	34	41	6	4	90
311	—	1	9	4	6	20
313	—	2	29	—	2	33
315	—	—	14	5	6	25
Total...	12	93	235	72	109	521

SUMMARY

1. Selfed and open-pollinated progeny of a procumbent plant of *Lespedeza cuneata* were studied.

2. From observation of selfed lines the procumbent plants appear to be homozygous.

3. Natural crossing of the procumbent plants with assurgent plants varied from 61.4 to 80.9%.

4. Petaliferous flowers may be naturally either self- or cross-pollinated. Progeny from apetalous flowers indicate that they are always self-pollinated.

5. Segregation in the F_2 indicates a complex type of inheritance.

6. Variation in segregation between F_2 lines suggests that pollen from a number of assurgent lines was effective in bringing about natural crosses.

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NUTRITIONAL FACTORS AFFECTING COTTON RUST[1]

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A NUTRITIONAL disease known as cotton rust is widespread throughout the Cotton Belt. In advanced stages it causes severe loss to the farmer in at least three ways: (a) A poor quality of cotton is produced because the bolls open only partially, the wet lint dries slowly and molds develop; (b) much of the cotton is left in the field because it is difficult to pick; and (c) the yields are usually lower than those obtained from cotton that is free of rust.

At the time this project was started in 1937, it was fairly well established that cotton rust was associated with a deficiency of potassium. However, in certain fields of cotton badly affected with rust, a double application of Chilean nitrate of soda completely eliminated the rust where applied to a portion of the field. This indicated that minor elements in sodium nitrate might be playing an important part in retarding the appearance of cotton rust. In some experiments on the Alabama substations, cotton fertilized with ammonium sulphate as the source of nitrogen rusted much more readily than adjacent plots fertilized with sodium nitrate. In fact, on certain soils, such as the Clarksville series, the use of ammonium sulphate as the source of nitrogen is avoided by many farmers because they believe that it increases the severity of cotton rust. Cotton that received large amounts of phosphate frequently rusted more severely than cotton on adjacent plots that received less.

It had been observed, also, that in many cases cotton rusted badly when planted on land from which peanuts had been dug frequently. These and other observations led to the decision to undertake a study of the factors affecting the development of cotton rust. The results of this investigation are reported herein.

EFFECT OF MINOR ELEMENTS ON COTTON RUST

During the summer of 1939, a total of 21 tests were started on fields of cotton known to be subject to severe cotton rust. Three 1/40-acre plots were laid off on each farm. Plot 1 received B, Cu, Mn, Zn, and Mg; plot 2 received the same as plot 1, except that Mg was omitted; and plot 3 received no minor elements or Mg. The elements were applied as follows: 10 pounds each of borax, copper sulphate, manganese sulphate, and zinc sulphate, and 160 pounds of magnesium sulphate. All three plots were fertilized uniformly with whatever fertilizer the farmer happened to be using.

The average yields for all the tests showed that minor elements gave an increase of 32 pounds of seed cotton per acre, and magnesium gave an increase of 88 pounds per acre. The development of cotton rust was observed four times during the season, and there was

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no visible evidence which indicated that either the minor elements or magnesium decreased or enhanced the severity of the rust.

EFFECT OF POTASSIUM ON COTTON RUST

The year 1937 was extremely favorable for the development of cotton rust. Cotton was heavily damaged over large areas of the state. Usually, in any infested field of cotton there would be portions free of rust, or there would be a few scattered individual plants not showing rust. (Individual green plants must be inspected carefully, because quite often the greenness is due to the absence of cotton bolls; consequently, the plant's requirement for potash is low. Only plants containing a normal number of bolls should be inspected for cotton rust).

Advantage was taken of the severe rust conditions in 1937 to collect samples of soil from 68 fields showing different degrees of severity of the rust. In each case two samples of soil were collected. One was taken near plants that showed no rust and the other was taken not over 50 feet away where plants showed rust. These soils were analyzed for exchangeable potash. The results (Table 1) showed that the exchangeable potash content of the soil taken from under healthy plants, even under the single rust-free plants in a large rusted area, was always higher than the potash content of soil taken from beneath adjacent rusted plants. Usually about half as much exchangeable potash was found in the soil under plants showing rust as under healthy plants.

Rust is usually severe on cotton planted after several consecutive crops of dug peanuts. Fourteen pairs of fields were sampled, one of each pair having had peanuts dug from it for at least the previous 4 years and the other having had no peanuts dug from it as far back as

TABLE 1.—*The amounts of exchangeable potash found in soils on which rust-free cotton was growing and in soils on which rusted cotton was growing.*

Condition of the cotton in the fields sampled	Number of fields sampled	Average pounds of exchangeable potash per acre	
		Under healthy cotton	Under rusted cotton
Solid fields of rusted plants containing occasional healthy plants	23	157	107
Solid fields of healthy plants containing occasional rusted plants	5	217	179
Solid areas of rusted plants adjacent solid areas of healthy plants	27	226	115
Fields of healthy plants and rusted plants separated by a fence or road	13	202	113
Average for all soils having a texture of sandy clay loam or heavier	33	257	133
Average for all soils having a texture of very fine sandy loam or lighter	35	169	91

the same date in the different plantings as in 1933. A summary of the yield data of these four plantings for the two years is shown in Table 6.

From Table 6 it can be seen that there might be competition between varieties A and B, D and E, E and F, F and G, and G and H. Of these, the competition between D and E is consistent throughout all four plantings. Variety D is a late variety, whereas E is a comparatively early variety. In yielding ability, however, it varies with the season. Earliness here may contribute greatly to competition. Apart from these two varieties, it is rather doubtful whether competition actually exists between the other varieties. Since the varieties used are farmers' varieties, they show variation in height of plant, earliness, type of head, etc. Perhaps this may explain some of the contradictory results obtained in these four plantings.

In order to pursue this question of varietal competition still further, another experiment was carried out in which 30 selected strains were used with varying earliness, height of plant, stooling ability, and yield of grain. Systematic arrangement was followed. Each strain was planted in five-row plats and was replicated five times. Each row was 17 feet long and 1 foot apart, and at harvest 1 foot from each end of the row was discarded, so that only 15 foot lengths were harvested for each row. Sowing for this experiment was done on June 6. The seedlings were thinned twice so that finally the distance between plants was 3 inches. The stand was thus made perfect. The precipitation during the growing season was very abundant so that the growth was at its maximum. If varietal competition existed, it should have manifested itself to its full extent. Stadler's method (9) for calculating the relation of competition to various characteristics of the competing varieties was followed closely, and the results are shown in Table 7.

TABLE 7.—*Correlation coefficient of competition with various characteristics.*

Character	Correlation coefficient
Yield	—.458
Height	+.165
Heading	+.577

When $n = 27$, r at 5% level of significance is .367 and at 1% it is .470 in Fisher's tables (1). These results differ greatly from those which were obtained with barley, oats, and wheat by Stadler (9), who found significant positive correlation between competition with yield and variable negative correlation with date of heading. With millet, the results were just in the reverse order and were significant in both cases. A positive correlation was obtained with height but it was insignificant. From these results it can be seen that the low-yielding and the late varieties are the ones which have, in general, profited from competition.

With maximum conditions for growth, competition between varieties does exist. Thus, in varietal trials with millet, even with random arrangement, it is wise to consider this problem.

PLANTING DISTANCE BETWEEN PLANTS IN VARIETAL TRIALS

In varietal trials with millet, the distance between plants is a problem to be considered. The common practice for the farmers in the vicinity of Kaifeng in Honan Province, China, is to put the millet in drills with rows about 7½ inches apart. In thinning, a clump of seedlings with varying numbers, usually from two to five, is left, leaving about 5 inches between clumps. In our varietal trials with this crop, the rows are farther apart, i. e., 1 foot. In the past, two plants in hills 4 inches apart or one plant in hills 3 inches apart were left in thinning, but the justification of this practice is open to question, hence an experiment was carried out in order to arrive at a solution. The variety used in this experiment was the selected strain No. 48 which is a high yielder, stools well, and matures fairly late. Five planting distances were considered, *viz.*, 2, 4, 6, 8, and 10 inches apart. These were arranged in a five by five Latin Square. Five rows formed a plat for each treatment. The rows were 17 feet long and 1 foot apart. In harvesting, only the central three rows in the plat were used, and 1 foot at each end of the row was discarded so as to avoid any effect of competition or border effect. The land on which this experiment was carried out was very level and was relatively uniform. Several uniform crops were grown prior to this experiment. Planting and cultivating were about the same as those described above for the other experiments, except that the seedlings were thinned to the distance required for each treatment. One plant was left in each hill. Table 8 gives the average yields of three central rows 15 feet long for the different planting distances.

TABLE 8.—*Yield in grams for different planting distances.*

Planting distance*	Yield, grams	Planting distance*	Yield, grams	Planting distance*	Yield, grams	Planting distance*	Yield, grams	Planting distance*	Yield, grams
B	257	D	245	E	182	A	203	C	231
E	230	A	283	B	252	C	204	D	271
A	279	E	245	C	280	D	227	B	266
C	287	B	280	D	246	E	193	A	334
D	202	C	260	A	250	B	259	E	338

*A = 2 in., mean yield 269.8 grams; B = 4 in., mean yield 262.8 grams; C = 6 in., mean yield 252.4 grams; D = 8 in., mean yield 238.2 grams; and E = 10 in., mean yield 237.6 grams.

TABLE 9.—*The analysis of variance of data in Table 8.*

Variation due to	Degrees of freedom	Sums of squares	Mean square
Columns	4	13601.36	—
Rows	4	6146.16	—
Treatments	4	4156.56	1039.14
Error	12	12667.28	1055.61
Total	24	36571.36	

From Table 9, it can be seen that the mean square of treatment is smaller than that of error, and certainly it denotes the insignificance of the treatments. The standard error of the mean of 5 is $\sqrt{\frac{1055.61}{5}}$ $= 14.53$. Any significant difference between two treatments would be $14.53 \times \sqrt{2} \times 2.18 = 44.79$ grams. Table 10 shows the actual difference between different planting distances.

TABLE 10.—*Difference in yield in grams between different planting distances with column used for standard of comparison.*

	B	C	D	E
A	7.0	17.4	31.6	32.2
B	—	10.4	24.6	25.2
C	—	—	14.2	14.8
D	—	—	—	0.6

It may be concluded therefore, that the yield of millet varies directly with the planting distance, but the difference is insignificant statistically even between treatments A and E which gave the highest and lowest yields, respectively. It can readily be seen that the number of plants in the row varies inversely as the planting distance, for we have the same length of row in each case. As the plants are farther apart in the row, stooling per plant might perhaps increase, thus making up in yield and offering an explanation for the lack of significance obtained with the different treatments. Table 11 shows the stooling per plant for the different treatments. In sampling, the first 10 plants of the row were counted and then subsequently averaged.

TABLE 11.—*Average number of stools per plant for different planting distances.*

Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	No. stools	Planting distance*	Average stooling
B	3.77	D	4.03	E	4.02	A	2.60	C	3.83	A	2.894
E	4.02	A	3.00	B	3.00	C	4.33	D	4.03	B	3.624
A	3.50	E	5.37	C	3.02	D	3.30	B	4.00	C	3.750
C	3.97	B	4.02	D	3.73	E	3.33	A	2.47	D	3.738
D	3.60	C	3.60	A	2.90	B	3.33	E	5.53	E	4.454

*See Table 8 for explanation of symbols.

As expected, the number of stools per plant varied directly as the distance between plants. However, treatment D does not follow this rule strictly, though is not very far off. The analysis of variance is given in Table 12.

When $n_1 = 4$, $n_2 = 12$, F at 5% level of significance is 3.26 and at 1% point is 5.41, according to Snedecor (8). Treatments in this experiment do have some significance. The significant difference

between two treatments is 0.797. Table 13 shows the comparative difference between the treatments.

In order to show the relation between the yield of each plat and the number of stools per plant for different planting distances, etc., analysis of variance and covariance is given in Table 14.

TABLE 12.—*Analysis of variance of data in Table 11.*

Variation due to	Degrees of freedom	Sums of squares	Mean square	F
Columns	4	2.04452	—	—
Rows	4	.34340	—	—
Treatments	4	6.13776	1.53444	4.58
Error	12	4.01712	.33476	—
Total	24	12.54280		

TABLE 13.—*Difference in number of stools per plant for different planting distances.*

	B	C	D	E
A	—.73	—.856	—.844	—1.560
B	—	—.126	—.114	— .830
C	—	—	.012	— .704
D	—	—	—	— .716

TABLE 14.—*Analysis of variance and covariance.*

Variation due to	Degrees of freedom	Sums of squares (x^2) A	Sums of products (xy) B	Sums of squares (y^2) C	B^2/A	
Columns	4	2.04452	139.0720	13601.36	—	—
Rows	4	.34340	1.5460	6146.16	—	—
Treatments	4	6.13776	—132.6160	4156.56	2865.38	3347.19
Error	12	4.01712	43.9940	12667.28	481.81	
Total	24	12.54280	51.9920	36571.36		
Treatment + error	16	10.15448	— 88.622	16823.84	773.407	

The regression coefficient $b' = \frac{43.994}{4.01712} = 10.951$. To test its significance, we have $B^2/A = 481.81$. Hence, the analysis of the yield error gives the following:

	Degrees of freedom	Sums of squares	Mean square
Due to regression	1	481.81	481.81
Due to deviations	11	12185.47	1107.77
Total error	12	12667.28	

This is not significant, of course, for the mean square due to regression is smaller than that due to deviations. Using the equation $Y = y - b'(x - \bar{x})$ to correct the mean yield y for regression, we get the results as shown in Table 15.

TABLE 15.—*Correction of the mean yield.*

Treatment	Stooling (x)	$x-\bar{x}$	$b'(x-\bar{x})$	Yield (y)	$Y=y-b'(x-\bar{x})$
A.	2.894	— .798	—8.7389	269.8	278.5
B.	3.624	— .068	— .7447	262.8	263.5
C.	3.750	.058	.6352	252.7	252.1
D.	3.738	.046	.5037	238.2	237.7
E.	4.454	.762	8.3447	237.6	229.3
	$\bar{x}=3.692$			$\bar{y}=252.22$	

The last column of Table 15 gives the yield for different treatments corrected for equal number of stools. Table 16 gives the analysis of variance corrected for number of stools.

TABLE 16.—*Analysis of variance corrected for number of stools ($C-B^2/A$ from Table 14).*

	Degrees of freedom	Sums of squares	Mean square
Treatment and error.	15	16050.433	——
Error.	11	12185.470	1107.77
Difference.	4	3864.963	966.24

This is again insignificant. We may conclude, therefore, that the number of stools might contribute some in making up the yield from what is lost in plant number per row when spacing between plants is farther apart. The yield, however, may depend on some other factors, such as the number of seeds per plant, the length of head, the height of plant, the weight of seeds, and what not. It is hoped that studies now in progress will throw some light on this problem.

In conducting varietal trials with millet, plants spaced 2 or 3 inches apart should give the best results. This will not only give the maximum yield, but it will also nullify the effect of missing hills, for there are more plants for the same length of row than when the spacings are farther apart.

RELATION OF YIELD COMPONENTS TO YIELD OF GRAIN

The yield of grain in millet is a very complex character. It is the end result and sum total of the activities of the plant. There are two main forces that determine the amount of seed produced, *viz.*, internal and external. The plant breeder is interested chiefly in the heritable traits of the strain or variety, the internal force. These traits should be manifested more clearly if the strains or varieties are grown under identical conditions.

In selection work with millet, however, one who merely goes to the field would have no idea whatsoever how to select the high-yielding plants. Also, in hybridization, the plant breeder will be at a loss to select the right parents so as to create a high-yielding strain artificially. For this reason, the following experiment was carried out to determine the components for yielding ability in millet.

Fifty selected strains were used in this study. The rows were 5 feet long and 1 foot apart, with hills 4 inches apart. There were altogether 10 replications for each strain, making 10 blocks. Each block accomodated 50 strains in a random fashion. In harvesting, all the plants in

TABLE 17.—*Average values of yield components for 50 strains of millet.*

Strain No.	Av. yield per plant, grams	Stools per plant	Height of plant, in.	Length of head, in.	Weight of 10,000 kernels, grams	Days to heading
469....	16.5	3.2	45.2	17.5	28.8	16.9
11....	15.2	3.3	38.3	13.7	26.4	11.6
162....	18.2	3.5	41.0	16.5	26.6	14.9
1082....	12.5	3.5	39.7	14.6	28.0	15.7
1211....	15.2	3.4	42.7	15.8	26.0	16.7
667....	12.1	5.8	33.5	9.8	22.9	13.2
655....	13.3	4.3	32.9	12.4	22.9	11.2
48....	14.9	5.6	40.1	13.6	23.4	18.4
724....	12.9	4.5	34.8	13.7	24.3	12.1
472....	16.8	4.3	41.2	16.1	27.8	15.9
635	13.1	3.7	43.4	13.5	26.5	20.6
771....	13.3	3.9	44.0	17.1	25.5	19.7
——*...	5.7	10.2	34.1	5.9	19.8	1.1
142....	13.4	2.5	38.9	17.5	26.2	12.2
1514....	14.0	2.7	43.4	14.8	26.5	14.6
704	10.0	2.4	34.9	10.0	25.1	10.5
51....	13.5	3.1	40.0	13.3	25.7	12.7
461....	15.3	3.8	41.2	15.8	27.9	15.7
1620....	10.9	3.3	40.3	15.0	23.5	19.9
721....	10.9	2.7	34.9	12.5	25.3	11.3
1588....	11.4	1.7	37.0	16.1	23.6	10.6
89....	13.7	3.9	40.3	18.2	23.7	14.9
71....	14.7	2.7	42.4	18.5	23.8	15.1
1149....	12.9	4.1	38.3	15.2	23.3	16.5
1419....	14.5	4.4	43.1	12.0	25.4	18.7
1286....	14.9	4.1	38.5	14.1	27.6	14.0
1567....	15.8	4.7	38.4	9.9	25.4	15.3
447....	10.9	2.7	33.5	11.5	23.7	10.3
781....	15.8	6.2	42.9	13.2	24.9	19.6
558....	13.9	4.8	34.4	12.7	25.9	12.9
475....	17.5	4.3	42.1	18.8	25.9	15.1
1138....	15.5	6.4	40.1	14.2	22.7	17.5
138....	12.4	3.4	37.9	14.4	27.3	12.5
133....	13.9	3.3	37.9	15.7	25.2	11.7
1246....	13.4	5.8	40.1	13.0	23.8	17.7
1401....	14.3	4.0	39.8	15.1	28.1	15.3
93....	14.1	4.0	38.3	14.8	24.6	15.1
581....	13.1	2.5	36.5	15.9	24.6	12.1
888....	17.7	4.6	42.9	17.6	25.2	16.5
1417....	14.7	5.3	43.4	13.5	23.5	19.6
1468....	13.5	2.5	39.1	14.6	26.0	13.1
1438....	12.4	1.4	42.9	18.2	27.5	15.3
615....	14.8	4.2	43.2	15.1	27.2	19.2
788....	14.2	5.2	40.5	13.1	26.0	20.1
12....	14.7	3.2	36.9	11.7	25.9	10.9
45....	13.7	3.6	42.7	16.1	23.7	15.6
679....	13.4	5.7	32.7	11.3	22.5	11.6
564....	17.6	6.1	36.5	13.1	25.3	13.7
1353....	16.0	4.3	39.4	15.3	27.5	16.6
1398....	15.2	4.6	42.3	11.7	26.1	17.7

*Hungarian millet.

each row, except one plant at each end, were pulled off by hand (10 plants as a general rule). Any plant adjacent to a missing hill was discarded. The height of the plants in inches, the number of stools per plant, the days to heading, the length of the longest head of each plant in inches, and the weight in grams per 10,000 kernels (unhulled) were obtained. Later, these were averaged and the results are summarized in Table 17.

SIMPLE CORRELATIONS

Each character was correlated with yield of plant and with the other factors in all possible combinations. Calculation of r was based on the method described in Wallace and Snedecor (10). Table 18 shows these correlation coefficients.

TABLE 18.—*Simple correlation coefficients for the different factors.*

	Height of plant	Days to heading	Length of head	Weight per 10,000 kernels	Yield of plant
Stooling	—.1610	—.0610	—.5441**	—.4862**	—.0514
Height of plant	——	.7421**	.5810**	.4447**	.5037**
Date of heading	——	——	.3980**	.3167*	.5345**
Length of head	——	——	——	.4211**	.4886**
Weight per 10,000 kernels	——	——	——	——	.4858**

A single asterisk indicates significant correlation and two asterisks indicate high significance. It can be seen from Table 18 that the yield of the plant is highly and positively correlated with all the factors named except number of stools which has a negative but insignificant correlation coefficient. Number of stools is negatively correlated with all the factors concerned, but only two, the correlation with length of head and with weight per 10,000 kernels, are significant. All other correlation coefficients between other factors are positive and significant.

MULTIPLE CORRELATION

The correlation between yield and the set of factors including stooling, height of plant, earliness, length of head, and weight of kernels was calculated, R being .7343. This is significant for when $n=45$, the 5% level of significance is .460 and the 1% level .527. ($n=44$ in our sample.) The relative effects of the five factors on yield of millet are shown in Table 19.

TABLE 19.—*Partial and zero order correlation coefficients of yield and other factors, together with standard regression coefficients.*

	Zero order correlation coefficient	Partial correlation coefficient	Standard regression coefficient
A, stooling	—.0514	.4185**	.4322
B, height of plant	.5037**	—.1211	—.1780
C, earliness	.5345**	.3034*	.3518
D, length of head	.4886**	.4409**	.4955
E, weight of 10,000 kernels	.4858**	.4679**	.4558

PARTIAL CORRELATION[4]

In order to study the association of each factor with yield independently of the variation of the other factors, partial correlation coefficients were calculated. These are also shown in Table 19.

Asterisks denote significance, as in Table 18. (n = 44 in our sample.) From these partial correlation coefficients thus calculated, we can conclude that yield of millet is really associated with weight of grain, length of head, number of stools per plant, and possibly earliness, after the other associations are taken into account. The height of plant, however, may have only an illusory relation to yield of millet, due to its association with other factors. The standard regression coefficients run almost parallel with the partial correlation coefficients.

It would mean, then, in selection work or selection of the parent for hybridization, that individual plants or varieties with good tillering, good length of head, heavy kernels, and fairly late in maturing are the ones to be selected. It should be kept in mind, however, that factors not studied here may play as important a rôle, if not more important, in determining yield. One must not be misled, therefore, by the results obtained from this experiment.

SUMMARY

In plat trials with millet, plats two rows wide and with the rows 15 feet in length proved most efficient. When land is not a limiting factor, however, plats of the same width but with rows 30 feet long, with a corresponding number of replications to the smaller plats, seemed to be the correct size and shape for these tests.

There seemed to be competition between varieties of millet. The competition coefficient was significantly and positively correlated with date of heading, but negatively with yield and insignificantly with the height of plant.

The closer the plants were set, the higher was the yield but less stooling per plant. By the use of analysis of variance, no significance was found in the yield of the different planting distances, i. e., 2, 4, 6, 8, and 10 inches apart, but there was a significant difference for the number of stools per plant for the different planting distances. The regression of yield on stooling was not significant.

Yield was correlated negatively with number of stools per plant, $r = -.0514$; but positively with the height of plant, $r = .5037$; days to heading, $r = .5345$; the length of head, $r = .4886$; and the weight of 10,000 kernels, $r = .4858$. The multiple correlation coefficient, $R = .7343$, was statistically significant. When the partial correlation coefficients were calculated, the yield of millet was correlated positively and significantly with the number of stools, length of head, and weight of 10,000 kernels, and possibly with the date of heading, but negatively and insignificantly with height of plant.

[4]Dr. C. Tu, Cotton Experiment Station, Hupeh Province, gave valuable suggestions for these calculations, and the authors wish to express their hearty gratitude.

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THE EFFECTS OF SODIUM CHLORIDE ON SOME TURF PLANTS AND SOILS[1]

V. T. STOUTEMYER AND F. B. SMITH[2]

RESEARCHES concerned with grasses for golf greens have not been developed until recently and the literature dealing with the effects of sodium chloride on the bent grasses and other turf plants commonly found on golf courses is rather meager. However, past studies on the salt tolerance of farm crops aid in understanding the problem.

Lipman, Davis, and West (6)[3] studied the sodium chloride tolerance of wheat, barley, and peas grown in nutrient solutions. A stimulating effect of sodium chloride was found for wheat up to concentrations of 8,000 p.p.m. and for barley up to 6,000 p.p.m., but increasing injury was noted with greater concentrations. The results obtained with peas were more variable but tended to show that above concentrations of 3,000 p.p.m. considerable injury was produced.

Yureva (11) obtained stimulation of tomato plants with concentrations of sodium chloride up to 0.2% of the dry weight of the soil.

Voelcker (10) found that applications of 500 pounds per acre of sodium chloride could be made without injurious effects to oats, wheat, lupines, and peas.

Breazeale (1) grew wheat in nutrient solutions and in soil. He found that the absorption of potassium was decreased when sodium was present in the solution used during the first period of growth before the plants were transferred to the soil. However, sodium assisted the absorption when the plants were grown in water cultures during both periods. The presence of sodium increased the transpiration and size of the plants even where there was an abundance of potassium.

Halket (3) found variations in salt tolerance between different species of plants and Hendry (5) found that varieties of legumes varied in their resistance to injury by sodium chloride in the soil.

Heald (4) summarized the literature on the effect of alkali salts on various crops, including the grasses and legumes. His classification of alkali resistance of plants shows that such plants as salt bushes and salt grasses are able to grow in concentrations of about 1.5%, while such crops as wheat, emmer, Kafir, alfalfa, field peas, vetches, horse beans, and sweet clover, are able to exist only in concentrations above 0.4%.

Sodium chloride has been used occasionally to control weeds in asparagus. Evans (2) stated "as long ago as 1895 it was found at the Vermont Agricultural Experiment Station that the orange hawkweed, a serious pest in pastures and meadows, could be destroyed without serious injury to the grass by sowing salt over the land at the rate of 3000 pounds per acre." The possible application of this method of weed control in bent grass putting greens was suggested by the fact that these grasses are known to grow in seaside regions where the soils often contain a high content of sodium.

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[3]Figures in parenthesis refer to "Literature Cited", p. 23.

Monteith and Dahl (8) reported that too great concentrations of any soluble salts, including sodium chloride, have resulted in injury to turf on golf courses where salt spray from the sea or an abnormal type of water supply causes an accumulation in the soil.

According to a number of greenkeepers trained in Scotland, the application of rock salt to greens was a common practice on some of the historic golf courses of that country. It is also said that a well-known Scotch golf architect mixed rock salt in the top soil of newly constructed greens. The purposes which these treatments were intended to serve are not clear. Practices of this kind are apparently unknown to American greenkeepers. The following experiments with sodium chloride on a number of turf grasses were performed in order to determine whether there is any basis for such practices.

EXPERIMENTAL

METHODS OF PROCEDURE

The effect of sodium chloride and phosphorus on soils and on turf plants commonly found on putting greens was studied in a series of greenhouse and laboratory experiments. The Dickinson fine sandy loam was selected for use in this study and was sieved through a ¼-inch screen and placed in 1-gallon earthenware pots in the greenhouse.

The soils were treated in duplicate pots as follows:

1. Check.
2. Phosphorus equivalent to 400 pounds of superphosphate per acre.
3. Phosphorus equivalent to 800 pounds of superphosphate per acre.
4. Phosphorus equivalent to 400 pounds of superphosphate and 2,000 pounds per acre of sodium chloride.
5. 2,000 pounds per acre of sodium chloride.
6. 4,000 pounds per acre of sodium chloride.

The phosphorus and sodium were applied as dilute solutions of orthophosphoric acid and sodium chloride one month after the plants had been started in the pots. The use of phosphoric acid did not cause serious changes in the reaction of the soil even though the Dickinson fine sandy loam used was not well buffered. With the higher rate of application of phosphorus the immediate change in reaction was less than pH 1.0 and by the end of the growth period the reaction was almost back to that of the original soil. The slight increase in acidity produced by the phosphoric acid was considered preferable for the purpose of this experiment to the addition of a superphosphate fertilizer containing calcium sulfate.

The four grasses, seaside bent, metropolitan bent, Kentucky bluegrass, and Bermuda grass, and Dutch white clover, were used. Seven plants of each species used were started in each pot. The plants of Bermuda grass and the two bent grasses were started by planting uniform cuttings of the stolons about 1 inch long. The Kentucky bluegrass was started by taking uniform plants from sod. The plants of Dutch white clover were seedlings about 1 inch in height and having about six to eight well-developed leaves. The plants were watered as necessary with distilled water, usually two or three times a week. Wire stakes and cotton twine were used to support the stolons of the Bermuda grass and the bent grasses to prevent them from rooting on the surface of the bench. The Bermuda grass was grown in a greenhouse kept at a night temperature of about 60°F. The other

three grasses and the clover were grown in a greenhouse in which the night temperature was about 50°F and were on a ground bench.

The plants were harvested after growing 120 days from the starting in the pots and a growing period of 90 days after the treatment with phosphorus and sodium chloride. The plants were cut off at the soil level, placed in paper bags, and later dried to constant weight at 70°C. The dry weight of the tops was used as an indication of the response of the various plants to the different treatments. The data obtained are presented in Table 1 and Figs. 1 to 3.

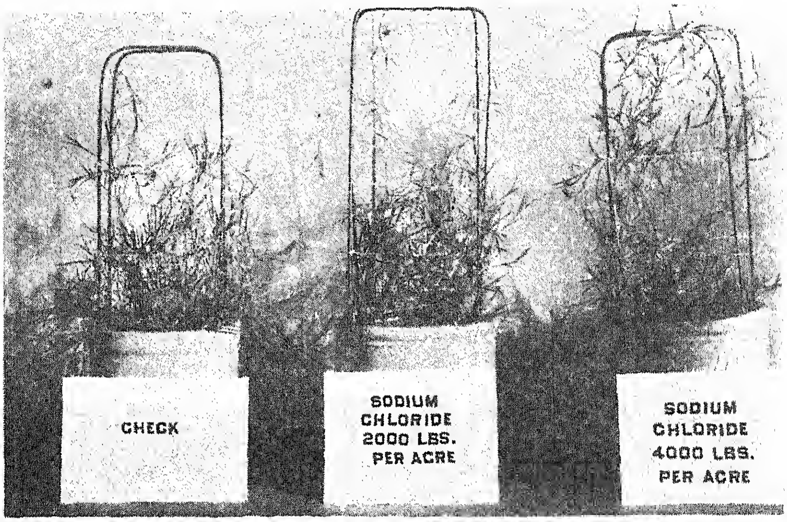

FIG. 1.—Effect of sodium chloride on metropolitan bent grass.

TABLE 1.—*Weight of plants in grams, oven-dry basis.*

Treatment	Kentucky bluegrass	Metropolitan bent grass	Seaside bent grass	Bermuda grass	Dutch white clover
Check	1.93 1.55	5.47 5.08	11.91 12.19	8.12 9.15	6.06 4.88
400 pounds superphosphate per acre	2.43 1.74	8.11 8.05	10.00 9.51	8.95 7.16	6.93 7.44
800 pounds superphosphate per acre	2.99 3.30	5.86 6.72	9.23 14.00	8.71 12.86	8.09 8.59
400 pounds superphosphate and 2,000 pounds sodium chloride per acre	2.17 2.12	6.26 6.80	10.19 10.31	8.26 10.74	5.20 5.47
2,000 pounds sodium chloride per acre	2.11 1.96	5.49 5.35	10.26 9.09	8.23 8.59	3.57 4.34
4,000 pounds sodium chloride per acre	0.44 0.21	4.51 5.79	8.13 8.26	6.50 5.43	2.36 2.45

RESULTS

The data show that phosphorus was effective in increasing the yield of all crops used and that the higher application was more effective than the lower application in all cases, except the metropolitan bent grass. Sodium chloride brought about decreases in yield of all crops, except Kentucky bluegrass at the lower rate of appli-

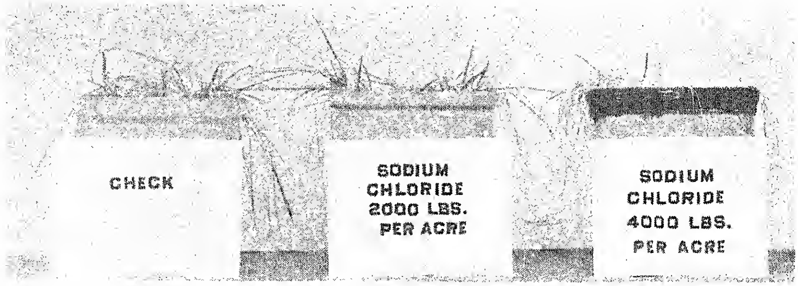

FIG. 2.—Effect of sodium chloride on Kentucky bluegrass.

FIG. 3.—Effect of sodium chloride on Dutch white clover.

cation. The higher rate of application of sodium chloride was quite toxic to Kentucky bluegrass and the Dutch white clover. The Bermuda grass and the two bent grasses, especially the metropolitan bent, were more tolerant of the sodium chloride. Two thousand pounds per acre of sodium chloride in addition to 400 pounds of phosphorus brought about significant increases in yields of Kentucky bluegrass, seaside bent, and Bermuda grass over the 400 pounds of phosphorus.

The analysis of variance of the data, Table 2, shows that the differences obtained with the phosphorus and the sodium chloride were highly significant. The relatively large interaction mean square in comparison with the small experimental error indicates that the different plant species reacted differently to a given treatment.

TABLE 2.—*Analysis of variance.*

Source of variance	Degrees of freedom	Sums of squares	Mean square
Total	59	629.38	—
Within classes	30	21.39	0.713
Between means of treatments	5	74.49	14.898
Between means of plant species	4	459.91	114.977
Interaction	20	73.59	3.68

EFFECT OF TREATMENTS ON SOIL CONDITIONS

The soils were sampled from the pots in which metropolitan bent grass was grown after the grass was harvested for a determination of reaction, available phosphorus, and chlorides. Loss on ignition, dispersion, and exchangeable bases were also determined on the check soil and the soil treated with sodium chloride.

The pH was determined by the quinhydrone electrode. Available phosphorus was determined by the Truog (9) method and chlorides were determined by the official method. The procedure recommended by Middleton (7) was followed to determine the percentage dispersion and total exchangeable bases were determined by electrodialysis. The results obtained are presented in Table 3 and Fig. 4.

TABLE 3.—*Changes in soil treatments.*

Treatment	pH		P, p.p.m.	Cl, p.p.m.	Loss on ignition %	Dispersed %
	At beginning	At end				
Check	6.00	5.95	25.71	75.5	3.99	6.3
400 pounds superphosphate per acre	6.00	5.75	37.19	77.0	—	—
800 pounds superphosphate per acre	6.00	5.75	68.95	75.0	—	—
400 pounds superphosphate and 2,000 pounds sodium chloride per acre	6.00	5.90	39.61	98.0	—	—
2,000 pounds sodium chloride per acre	6.00	5.95	26.77	102.0	—	5.3
4,000 pounds sodium chloride per acre	6.00	5.95	24.15	121.5	4.06	6.8

The data in Table 3 show that the addition of phosphoric acid increased the acidity of the soil slightly, but the addition of sodium chloride did not bring about a change in the reaction. The soil treated with phosphorus equivalent to 400 pounds per acre and with sodium chloride contained slightly more soluble phosphorus than the soil treated with the phosphorus alone. The soil treated with 2,000 pounds of sodium chloride contained slightly more soluble phosphorus than the soil treated with the phosphorus alone. The soil treated with 2,000 pounds of sodium chloride contained slightly more soluble phosphorus than the check soil. Apparently the sodium chloride increased the solubility of the phosphorus or decreased the utilization of phosphorus by the metropolitan bent grass.

The addition of sodium chloride brought about an increase in the concentration of chlorides in the soil, but the loss on ignition and the percentage dispersed were not materially affected by this treatment. However, the total exchangeable bases of the soil were reduced by treatment with sodium chloride, the reduction in bases being about 4.0 milliequivalents with the 4,000 pounds per acre treatment of sodium chloride.

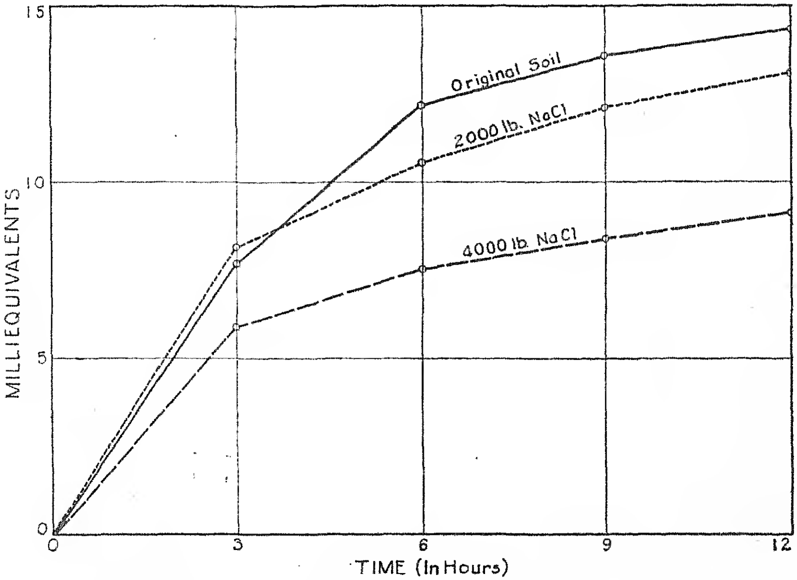

FIG. 4.—Effect of sodium chloride on the exchange capacity of Dickinson fine sandy loam.

PLAT EXPERIMENTS

In order to make a test of the effect of sodium chloride on grass turf under field conditions, eight plats each 10 feet square were located in a random arrangement over an area of metropolitan bent turf which was heavily and rather uniformly mixed with some Dutch white clover and Kentucky bluegrass. The top soil on this area had been prepared by composting and corresponded closely to some of the soil mixtures used for putting greens. The grass was maintained somewhat higher than putting green length during this experiment.

The following treatments were made with one replication of each:

1. Check.
2. Sodium chloride applied at the rate of 2,000 lbs. per acre.
3. Sodium chloride 4,000 lbs. per acre.
4. Sodium chloride 6,000 lbs. per acre.

The applications were made during the first week of May, 1935. In order to avoid burning, the salt was divided into two equal amounts and applied on two successive days. It was washed off the foliage and into the ground immediately with water from a garden hose. The

results were somewhat similar to those obtained in the greenhouse tests, except that the responses were obtained with lower concentrations of the salt. The white clover disappeared at once from all the salt-treated plats and was absent during the remainder of the season. Kentucky bluegrass, on the contrary, showed a marked stimulation on the 2,000- and 4,000-pound treated plats and did not disappear on any of the plats except those receiving 6,000 pounds per acre. The bent grass continued to make a normal growth under the 2,000- and 4,000-pound treatments. All turf plants showed injury on the plats receiving 6,000 pounds per acre.

DISCUSSION OF RESULTS

Highly significant differences were obtained with different treatments and with different plant species. Phosphorus was effective in stimulating the growth of all plants, especially Kentucky bluegrass and Dutch white clover. Sodium chloride at the rate of 4,000 pounds per acre was toxic to all plants, especially Kentucky bluegrass and Dutch white clover. The sodium chloride was less toxic to all plants when applied with phosphorus than when applied alone. The metropolitan bent grass was more tolerant of the sodium chloride than the other grasses.

The continued use of sodium chloride or the use of sodium chloride in any considerable amounts on the soil will bring about a replacement of bases with sodium. A soil complex saturated with sodium becomes dispersed or deflocculated after the removal of the excess salts by leaching and the resulting physical condition of the soil is poor.

The tests made on this soil after treatment with sodium chloride did not show any considerable change in the physical condition of the soil. However, the content of exchangeable bases was decreased. This decrease in the amount of exchangeable bases was probably caused by a replacement of bases in the organic exchange complex by sodium. The sodium-saturated organic complex is soluble and this would undoubtedly result in a decrease in the absorption complex. It is also possible that the exchange complex became more highly saturated with hydrogen, but this seems unlikely since the reaction of the soil was not changed. Since the loss on ignition was not decreased by the sodium chloride treatment and since the chloride content of the soil was increased, there was no considerable leaching of the soil by watering and there was an excess of sodium chloride present. The soil contained only 12.7% of silt and clay. The presence of the excess sodium chloride and the small amount of silt and clay explain the low percentage dispersion and the reason why the dispersion was not increased.

SUMMARY AND CONCLUSIONS

The effect of phosphorus and sodium chloride on some common turf plants and soils was studied in a series of greenhouse and laboratory experiments. Phosphorus stimulated the growth of the plants, but sodium chloride in the concentrations used was apparently toxic

in some cases and stimulative in others. The toxicity of the sodium chloride was decreased somewhat by the phosphoric acid.

Metropolitan bent grass was more tolerant to sodium chloride than Kentucky bluegrass, seaside bent grass, Bermuda grass, or Dutch white clover.

Highly significant differences in the effect of phosphorus and sodium chloride on the growth of the different plants were obtained. The total exchangeable base content of the soil was decreased by the treatment with sodium chloride. The results indicate that sodium chloride alone or in combination with phosphate fertilizers may be used on sandy soils for metropolitan and seaside bent grass. However, these experiments are preliminary in nature and further work with nitrogen and potassium fertilizers applied along with salt and on different soil types is necessary to permit of broader conclusions and such work would certainly be very desirable.

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A STUDY OF THE ASSOCIATION BETWEEN MEAN YIELDS AND STANDARD DEVIATIONS OF VARIETIES TESTED IN REPLICATED YIELD TRIALS[1]

F. R. Immer[2]

SINCE the introduction of the "Analysis of Variance" by Fisher (2),[3] the randomized block and latin square arrangements of plats have enjoyed widespread use for comparative variety trials. The principles involved in these methods have, in the main, been tested with data from actual field experiments and found to be entirely valid for such data.

In 1931, Tedin (5), using published uniformity trial data, furnished experimental proof of Fisher's theoretical considerations regarding the necessity of a random arrangement of plats. Tedin demonstrated that with a random arrangement alone was it possible to obtain a valid estimate of error.

In 1933, Eden and Yates (1), using height measurements of wheat plants from different plats, made a practical test of the validity of Fisher's "Z" distribution for small samples drawn from a population which was definitely skew. They found that the "Z" distribution could be safely applied to such data. Fisher, Immer, and Tedin (3) had previously shown a negative skewness of plant height measurements taken from different plats, the plats with the taller plants being the least variable.

Another test of considerable importance, which can be made only with data from practical field trials, involves the determination of the independence of the means and standard deviations of individual varieties being compared. In comparative variety trials the number of strains, or varieties, to be tested is usually large and the number of replications must, of necessity, be small. This is true particularly of yield trials involving plant breeding material. In calculating an experimental error from such tests, it is assumed that the errors of the separate varieties are random sampling deviates from a population having the same errors, although their means differ. On this assumption is based the calculation of a generalized error for the entire experiment.

In 1928, Hayes and Immer (4) studied the relationship between mean yield and probable error of varieties of cereals tested in yield trials. They separated the varieties into three groups, *viz.*, those falling within the low, middle, and high third of the total range in yield of the varieties in the test. A separate probable error was calculated for each group. Such computations were made in eight separate tests. A general tendency for the errors to increase as yield increased was found. Comparing the intermediate group with the high-yield-

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[3]Figures in parenthesis refer to "Literature Cited", p. 27.

ing group, the high group had the higher error in three and a lower error in five of the eight experiments. In the comparison of the low and intermediate yield groups, however, the low group had the lower error in seven of the eight tests. It is with a further test of the association of mean yield and standard deviation of varieties in yield trials that the present paper is concerned.

MATERIALS AND METHODS

The data used consisted of bushel yields of corn, barley, oats, flax, and spring wheat strains and varieties tested in comparative yield trials by the Minnesota Agricultural Experiment Station. The tests were made at University Farm or at the branch stations located at Waseca, Morris, and Crookston. From 26 to 286 strains were involved in the different variety trials. In 14 of the 16 tests but three replicated plats of each strain were involved while four replicated plats were used in the other two tests. Since 1931 a random arrangement of plats within each replication series was used, while prior to 1931 the arrangement of the strains followed a systematic order.

The yield data for barley, oats, flax, and spring wheat were taken from rod row trials. The corn experiment consisted of plats of 12 hills each. The mean yield and standard deviation was calculated separately for each strain, or variety, within each test. The means and standard deviations of the separate strains were then correlated.

EXPERIMENTAL RESULTS

The correlation coefficients varied from + 0.2374 to — 0.3190. Only 5 of the 16 coefficients exceeded ± 0.10 and of these, 3 were positive and 2 negative.

In 1931, the same 62 strains of spring wheat were tested at University Farm, Waseca, Morris, and Crookston. The correlation coefficients in these four tests were all positive but less than 0.08. In 1932, the same 50 strains of spring wheat were tested at the same four stations. The correlation coefficients were — 0.2865 and — 0.0358 at University Farm and Morris, respectively, and + 0.2374 and + 0.2112 at Waseca and Crookston, respectively.

In the spring wheat tests referred to above the mean yield of each variety as an average of the four stations was correlated with the mean standard deviations of the same varieties for the same tests. The mean standard deviation was obtained by averaging the four variances of each variety and extracting the square root. The correlation coefficients between the mean yields of the strains as an average of the four stations (based on 12 plats each) and the mean standard deviations were — 0.0385 in 1931 and + 0.1713 in 1932.

The average correlation coefficient for the 16 tests given in Table 1 was obtained by transforming the values of r to Fisher's "Z" and calculating the weighted average of "Z" (2, page 191). The weighted average of "Z" was + 0.0373 ± 0.0311, a non-significant value. The average value of r, by transformation from Z, was also + 0.0373. This average, based on 1,087 individual means and standard deviations, indicates definitely that within the range of yields obtained in these yield trials the standard deviations of the separate varieties tend to be independent of the mean yield of the varieties.

TABLE 1.—*The coefficients of correlation between means and standard deviations of strains and varieties tested in regular yield trials.*

Crop	Place grown	Year grown	Number of strains	Number of replications	Yield in bushels per acre		Correlation of means and standard deviations
					Mean	Range	
Corn	Waseca	1934	69	4	40.33	28.6–50.6	—.0227
Barley	University Farm	1928	66	4	56.41	41.8–68.4	—.3190
Barley	University Farm	1930	63	3	47.71	22.9–64.3	.0677
Barley	University Farm	1932	49	3	44.06	18.3–68.0	.1420
Oats	University Farm	1927	286	3	45.54	20.8–79.5	.0871
Flax	University Farm	1930	26	3	17.90	7.4–25.7	.0355
Flax	University Farm	1932	54	3	17.87	8.9–25.8	.0723
Spring wheat	Crookston	1934	26	3	36.45	31.2–41.7	.0949
Spring wheat*	University Farm	1931	62	3	16.60	10.5–20.6	.0419
Spring wheat*	Waseca	1931	62	3	25.26	18.1–30.6	.0755
Spring wheat*	Morris	1931	62	3	19.44	14.3–25.8	.0628
Spring wheat*	Crookston	1931	62	3	23.95	17.1–31.5	.0421
Spring wheat†	University Farm	1932	50	3	23.59	17.9–29.7	—.2865
Spring wheat†	Waseca	1932	50	3	23.65	15.7–30.7	.2374
Spring wheat†	Morris	1932	50	3	25.01	14.1–30.9	—.0358
Spring wheat†	Crookston	1932	50	3	22.09	18.0–29.3	.2112
Av.							.0373

*The same 62 strains tested at the four stations.
†The same 50 strains tested at the four stations.

CONCLUSIONS

It seems safe to conclude that in variety trials in which the range in yield is not too great, the assumption of independence of mean yields and standard deviations of the separate varieties is valid.

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THE INFLUENCE OF SEED INOCULATION UPON THE GROWTH OF BLACK LOCUST SEEDLINGS[1]

D. W. THORNE AND R. H. WALKER[2]

THE ability of black locust (*Robinia pseudoacacia*) to utilize atmospheric nitrogen, together with its spreading root system, makes it particularly adapted for soil conservation work. Mattoon (5)[3] reported that it is found widely distributed over the eastern half of the United States, but that its native home was probably in the Appalachian Mountains, including the outlying Piedmont region. He described it it as growing best on well-drained, neutral soils, and stated that it has been recommended for planting from the New England states south to Georgia and west to Texas, Missouri, and Illinois.

The important symbiotic relationship between the black locust and the legume root-nodule bacteria has been pointed out by a number of investigators. Nobbe, *et al.* (7) found that well-nodulated black locust seedlings produced a better vegetative growth than similar plants without nodules but which received either ammonium sulfate or calcium nitrate fertilizer. Mattoon (5) concluded that the presence of rhizobia in the roots of the locust seemed to give it a greater resistance toward attack by the locust borer. McIntyre and Jeffries (6) found that nodulated black locust trees increased the nitrogen content of the soil and made it more productive. They reported that the growth rate of catalpa and the amount of nitrogen in the soil decreased as the distance from the adjacent black locust plantings increased.

Some investigators in working with black locust have failed to take advantage of this symbiotic relationship. Ware (10), in a recent bulletin, reported that the locust grew but very poorly in the depleted soils of Alabama unless it received a complete fertilizer. He advocated about 0.4 pound per plant of a 2–8–4 fertilizer supplemented with about 0.1 pound of nitrate of soda. Accordingly it was concluded that the cost of establishing the locust satisfactorily makes it too costly to use in large scale reforestation programs, or for large-scale plantings on abandoned agricultural land. Throughout the report, however, no mention was made of the use of any bacterial inoculant for the plants. It appears reasonable that proper inoculation of the seed might make the use of much of the expensive fertilizer materials unnecessary and also insure a more vigorous continued growth of the plants.

Many experiments have been conducted which have shown the advantage of seed inoculation in the growing of the common legumes. No papers are available, however, which report a similar study of the

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[3]Figures in parenthesis refer to "Literature Cited", p. 34.

black locust. The present extensive use of this plant makes such an investigation desirable.

The expediency of inoculating legumes when strains of the proper root-nodule bacteria are known to be present in the soil has long been a question of soil management regarding which very little data are available. The present investigation was confronted by such a situation and the results are of corresponding interest.

ISOLATION AND STUDY OF BLACK LOCUST ROOT-NODULE BACTERIA

The black locust organism used in this investigation was isolated from nodules collected from the roots of black locust trees occurring in central Iowa. Different strains were isolated on yeast extract-mannitol medium 79 of Fred and Waksman (3) upon which the organism grows readily and produces a heavy growth. The rapid, luxuriant growth produced, together with the ability of the organism to produce a typical serum zone in skimmed milk cultures, seems to justify placing it with the group of "fast growing" *Rhizobium.*

Maassen and Müller (4) and Burrill and Hansen (1) placed the black locust in a separate cross-inoculation group. In the present investigation their results were at least partially verified. Black locust seeds, sterilized with hydrogen peroxide (9), were planted in sterile pots of sand. These were inoculated in triplicate with each of the different strains of organisms isolated from the root-nodules of black locust and also with strains, known to be effective, representing each of the six recognized species of *Rhizobium* and also the organisms belonging to the dalea and cowpea cross-inoculation groups. The cultures of black locust organisms induced good nodulation on the black locust seedlings, but no nodules were produced by any of the other species of bacteria used.

Further tests also showed that the cultures of locust organisms employed would not produce nodules on plants representing any of the first eight cross-inoculation groups of legumes listed by Fred, Baldwin, and McCoy (2). No further tests were made to study the possibilities of cross inoculation with the plants of the several other groups of less common legumes.

INOCULATION OF BLACK LOCUST IN FIELD TRIALS

As a part of the federal soil conservation program, millions of black locust seedlings are being grown for use in checking soil erosion and for reforestation purposes. Three nurseries have been established in the near vicinity of Ames, Iowa, by the Soil Conservation Service and the Forest Service of the U. S. Dept. of Agriculture to produce locust seedlings for these purposes. The present investigation was carried out in cooperation with the workers at two of these nurseries.

Inasmuch as it has not been customary on these projects to inoculate any of the locust seed, a good opportunity was furnished for studying the results of such a practice. At the time of planting in the spring of 1935 the seeds used for part of the beds were inoculated with a culture of black locust root-nodule bacteria. After two months, the

size, appearance, and nitrogen content of the seedlings from the beds planted with inoculated seed in comparison with the same properties of plants from beds not planted with inoculated seed indicated distinct advantages from inoculation. This is of particular interest inasmuch as most of the plants throughout both nurseries bore some nodules as a result of the natural occurrence of the proper legume bacteria in the soil.

The black locust seeds were planted in beds 3 feet wide with spaces of 2 feet between beds. Field I was located on a recent alluvial deposit of a fine sandy loam over soil of the Wabash series, southeast of Ames near the Skunk River. The soil was low in organic matter and nitrogen, the nitrogen content being only 0.089%. The reaction was slightly alkaline, pH 7.69. In general, this soil may be rated as one of comparatively low fertility. The seeds used for the planting of three of the beds were inoculated with a culture of black locust root-nodule bacteria. The inoculated beds were located at random in the nursery.

Field II was located about 1 mile west of Ames on Clarion silt loam. The soil was of rather high fertility. The nitrogen content was 0.303% and the reaction slightly acid (pH 5.95). The seeds were planted in long beds as in field I. Three adjacent beds in the field were planted with inoculated seed and the remainder of the beds received no pure culture of the organisms.

Observations were made and data taken of the seedlings about 10 weeks after planting. It was found that nodules occurred on the plants throughout both fields regardless of whether or not the seed was inoculated. In spite of this fact, some rather distinct differences were observed. In field I the plants growing from the inoculated seed were easily distinguished from the other plants of the field. Their greater height, darker green color, and healthier appearance contrasted with the yellowish color and smaller size of the plants from the uninoculated seed made the beds of seedlings which had been inoculated easily discernible from some distance across the field. Such a contrast was not so evident in field II. All plants in this field had a deep green color and thrifty appearance and differences in height of the plants as a result of the two treatments were not so large.

In each of the two fields 100 plants were dug at random from the beds planted with inoculated seed. The same number of plants was similarly taken from the adjacent beds which were planted with the uninoculated seed. These four groups of plants were taken to the laboratory, washed free of soil, the total length of each plant recorded, and the length of the roots measured. The number of nodules per plant and the distance from the ground line to the first nodule were determined. These data were analyzed statistically. The mean and standard deviation were calculated for each group of measurements. The difference between the means for each determination on the seedlings which had received inoculum and those which had not was found and the degree of significance of these differences calculated. The data, including the results of the statistical analyses, are given in Table 1.

TABLE 1.—*Total plant lengths, root lengths, and the number and location of nodules on black locust seedlings growing from inoculated and non-inoculated seed.*

	Total plant length, cm		Root length, cm		Distance from soil line to first nodule, cm		Nodules per nodulated plant		Percentage of plants nodulated
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.	
Field I									
Inoculated	33.48	4.79	16.21	2.59	3.30	1.46	8.93	6.53	98.0
Not inoculated	23.45	2.74	14.48	2.07	6.60	2.73	3.43	2.31	75.0
Mean difference	10.03**	—	1.73	—	3.30**	—	5.50**	—	—
Field II									
Inoculated	38.00	7.95	15.94	3.77	1.92	0.56	9.76	5.54	100.0
Not inoculated	30.00	4.85	14.32	2.98	3.66	2.52	4.57	2.91	94.0
Mean difference	8.00	—	1.62	—	1.74*	—	5.19**	—	—

*Mean difference is significant.
**Mean difference is highly significant.

The greater significance in mean differences between inoculation and non-inoculation of seeds in field I as compared to field II corresponds to the generally accepted principles of legume inoculation. The higher nitrogen content of the soil of field II, presumably, made the plants of that field less dependent upon symbiosis with root-nodule bacteria than the plants of field I.

The groups of plants from which the data of Table 1 were taken were dried at 95°C and the dry weight of each group determined. The nitrogen content was determined by the Kjeldahl method. The resulting data are given in Table 2. The last column in the table records the percentage increase in total nitrogen in the plants receiving the bacterial cultures over those not receiving them. These data seem to indicate that inoculation provided the plants with a more efficient strain of organisms than was originally present in the soil. The evidence upon which this conclusion is based is more pronounced in the data from field I. This is to be expected for there the plants were forced to rely to a greater extent than in field II upon the symbiotic relationship with the legume organisms for their nitrogen supply.

The location of the nodules on the plants as a result of the inoculation and non-inoculation treatments was quite distinctive. The plants which had received the pure culture inoculum had more nodules per plant than those plants which did not receive it. The nodules were also located nearer to the tap root and the surface of the soil than the nodules which resulted from the native soil flora. Root systems representative of plants receiving each of the treatments are shown in Fig. 1.

Inasmuch as the black locust is being used rather generally for the reclamation of badly eroded land, a study of the growth of the seedlings on soil of low fertility seems of greater practical interest than its growth on more fertile soil. For this reason a more complete study was made of the seedlings of field I than of field II.

TABLE 2.—*Dry weights and nitrogen contents of black locust seedlings growing from inoculated and non-inoculated seed.*

	Nitrogen content of soil, %	Weight of 100 plants, grams	Nitrogen content of plants, %	Increase in total nitrogen from inoculation, %
		Field I		
Inoculated	0.089	23.43	3.06	297.2
Not inoculated	—	8.69	2.09	—
		Field II		
Inoculated	0.303	31.16	3.22	80.4
Not inoculated	—	21.15	2.63	—

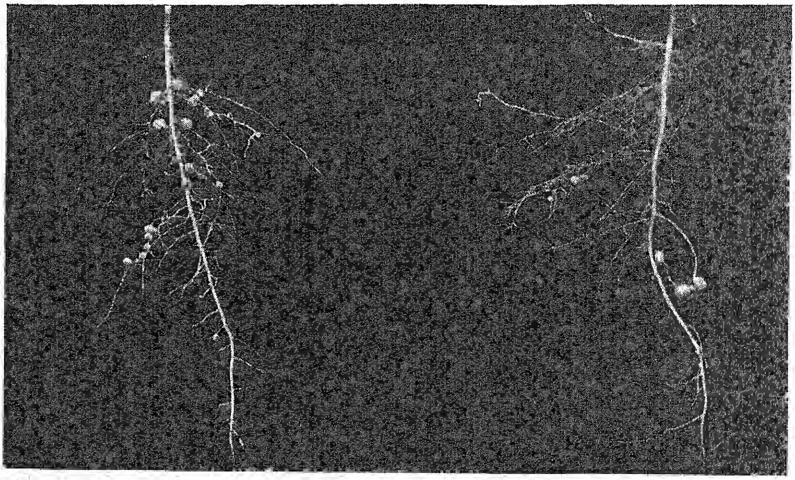

FIG. 1.—Nodulated roots of black locust seedlings.

The root on the left is representative of those grown from seed inoculated with a pure culture of the black locust root-nodule bacteria. The root on the right is representative of those grown from uninoculated seed.

At about the same time that the data of Table 1 were taken the number of plants per square foot of the nursery beds was determined for those beds which had received the pure culture inoculum and the adjacent beds which had not. This was accomplished by counting the number of plants within a circular hoop of known area dropped at random at 10 different places on each bed. Random measurements were also made of the heights of 100 plants of each bed upon which relative counts were made.

Shortly after the above data were collected the soil became very dry for a period of about a month. As a result large numbers of the apparently less vigorous seedlings which had not received any pure culture inoculum died. This made the beneficial effects of inoculation

appear even more prominent. To determine these differences, counts of plant stands were again made and the relative heights of the plants measured about 5 weeks after the first data were collected. The data for the plant heights and relative stands taken at the tenth and fifteenth weeks after planting were analyzed statistically. The results are shown in Table 3.

TABLE 3.—*The heights and stands of black locust seedlings growing from inoculated and non-inoculated seed planted in soil of low fertility (field I).*

	Seedlings at 10 weeks of age				Seedlings at 15 weeks of age			
	Plant length in centimeters		Plants per square foot		Plant height in centimeters		Plants per square foot	
	Mean	S. D.	Mean	S. D.	Mean	S. D.	Mean	S. D.
Inoculated	18.95	5.26	42.10	14.18	26.91	9.19	36.67	13.61
Not inoculated	12.21	3.10	40.82	13.57	17.59	4.69	26.86	12.17
Mean difference	6.74**	—	1.28	—	9.32**	—	9.81**	—

**Mean difference is highly significant.

It is notable that whereas at the tenth week there was no significant difference in the mean number of plants per square foot of bed between the inoculated and non-inoculated beds, 5 weeks later the mean difference was highly significant. The data indicated about a third more plants in the beds which had received the inoculum. The mean difference in plant height was further accentuated in the five additional weeks of growth.

DISCUSSION

It appears that the beneficial results from the inoculation of black locust under the conditions of these experiments might be accounted for by one or both of the following reasons: (a) Inoculation placed a larger number of the black locust root-nodule bacteria in contact with the seed, resulting in an earlier nodulation of the seedlings and a greater number of nodules per plant; or (b) the strain of organisms furnished in the pure culture inoculum was more efficient than the average of the strains naturally occurring in the soil. It has been shown by many investigators (2) that there is considerable variation among the strains of any species of *Rhizobium* in their ability to benefit the host plant.

Turner (8) and Ware (10) emphasized the possibilities of growing black locust on highly acid soils. They did not, however, take into consideration the possibilities of bacterial symbiosis. Black locust is usually planted in eroded or depleted soil for the purpose of checking erosion. It seems, therefore, very important that the plants be well inoculated in order to obtain the best growth on these poor soils and for the soil to derive the maximum benefit from the plants. Inasmuch as many of these soils are acid, the application of limestone would probably be necessary in such cases in order to realize the best results from inoculation.

SUMMARY

Experiments conducted in cooperation with the U. S. Dept. of Agriculture Soil Conservation Service and Forest Service nurseries in Iowa have shown the advantages of inoculation of black locust seeds. Although there was considerable nodulation of seedlings throughout the nurseries as a result of the presence of root-nodule bacteria in the soil, seedlings growing from the inoculated seed made better growth and fewer died during the summer months than did the seedlings which were infected only with the native microflora of the soil. The increase in total nitrogen content of the seedlings as a result of inoculation was 297.2% on a soil of low fertility and 80.4% on a soil of rather high fertility.

The nodules formed from pure culture inoculation were more numerous and were generally located much nearer the tap root of the host plant and closer to the surface of the soil than the nodules induced by the rhizobia occurring in the soil.

Two reasons for the beneficial results from inoculation were suggested, *viz.*, (a) inoculation resulted in a greater number of nodules located nearer the tap root of the plant; and (b) the strain of organisms supplied in the pure culture inoculum was more efficient than the average of the strains of this species originally present in the soil.

Cross inoculation tests showed that *Rh. meliloti*, *Rh. trifolii*, *Rh. leguminosarum*, *Rh. phaseoli*, *Rh. japonicum* from both soybeans and cowpeas, *Rh. lupini*, and the root-nodule bacteria of dalea (Wood's clover) were not capable of producing nodules on black locust roots. Furthermore, the black locust root-nodule bacteria were not capable of producing nodules on the leguminous symbionts of the above species of bacteria.

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ENVIRONMENTAL FACTORS AFFECTING SEED SETTING IN SUGAR BEETS[1]

S. M. RALEIGH[2]

NEARLY all improvement in sugar beets has been accomplished through selection. The necessity for controlling the male as well as the female parentage in breeding heterozygous material is an accepted principle in crop improvement.

The purpose of these investigations was to find a method by which sugar beets could be successfully selfed for carrying on breeding investigations under Minnesota conditions, without using space isolations.

REVIEW OF LITERATURE

Through selection, strains and varieties of sugar beets with high sugar content have been developed. The sugar content of the high group selections by various German seed companies has been summarized by Becker-Dillingan (5).[3] In 1818 the sugar content was 6.0%. As a result of selection of desirable sized and shaped beets, the sugar content was 9.8% in 1848. By juice polarization the sugar content in 1888 was 13.7% and by pulp polarization selection the sugar content had increased to 21% by 1929–30. But Vilmorin (27), in 1856, reported finding individual beets with a sugar content of 21.0%.

Very little progress has been made in breeding sugar beets by the hybridization method. Roemer (16), in 1915, reported that beets degenerated when inbred. Werner (28) obtained better results by selection. Strains of sugar beets inbred by Dudok Van Heel (8) generally yielded less than open-pollinated commercial seed although not because of degeneration.

Inbred strains obtained in Italy by Munerati (12) were less vigorous than normal beets, and crosses gave increased vigor. Darwin (6), in 1876, obtained increased vigor by crossing. By selection and inbreeding, Townsend (24) developed lines within three generations which would produce single germ seed balls in 75% of the cases. The "elites" reported by Sunderlin (23) obtained by hybridization of different lines or families gave better yields, as a rule, in comparison with strains obtained by mass selection.

When Shaw (19) planted beets 2 miles apart, the highest percentage of seed set was 2.29. Many of the plants were sterile.

Grocery bags were used successfully as isolators by Townsend and Rittue (25) in 1904. The seed balls with more than one flower were removed. This left only a small number of seed balls per bag. In this work bags were removed after pollination.

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[3]Figures in parenthesis refer to "Literature Cited", p. 50.

The investigation of Shaw (18) proved that thrips were important in pollinating sugar beets. He suggested the use of cotton around the stem and tying the bag tightly.

In 1926, Stewart and Tingey (22) used 2-pound grocery bags on about 75 beets. They state, "As a whole it may be said that sugar beets self-fertilized rather freely by this method under 1926 conditions at Logan". Stewart (21), in 1933, reported, "The production of seeds under bags has not been successful in several localities where tried."

The majority of the plants isolated with glassine bags by Reed (15) failed to produce seed and no plant produced more than 20 seeds.

Parchment isolators were used successfully by Nilsson (13, 14) at Svalöf. In 1916, 74% of the plants set seed under isolators. The branches were cut back leaving as many as 343 glomerules per isolator. When the branches were cut back leaving 10 or less glomerules, a much higher percentage of isolators with seed was obtained. In 1919 and 1920 two branches of related selfed plants were enclosed in the same isolator. As high as 98% of the isolators with less than 10 glomerules per branch set seed.

At Michigan, Down and Lavis (7) obtained no seed from plants isolated with parchment. The mother beets under tent isolators averaged 31.6 grams of seed per plant. Upon growing this seed it was found that, of the seed germinating, 41% had crossed with garden beets grown under adjacent tents. The data presented by Kohls and Down (11) indicated that inbreeding and selection of mother beets result, for a time at least, in an increase in the average production of seed per mother beet.

The tent isolators used by Vilmorin (26) were very satisfactory if the beets were planted early so that the plants flowered before hot weather. Tents with a window in the top used by Munerati (12) were satisfactory in Italy.

Archimovitch (1, 2, 3, 4), working at the Belaya Cerkov Plant Breeding Station in Ukraine, has used many types of tent isolators and parchment bag isolators. The wooden isolators were a total failure because of high humidity. Tent isolators. were very good, although they permitted some crossing. Under tent isolators he reports 82.4, 90.8, 87.2, and 72.2% of the plants with glomerules for 1926, 1927, 1928, and 1929, respectively, and with parchment isolators 5.5, 10.4, 28.4, 27.1, 31.8, and 22.6% of the isolators produced glomerules for 1925 to 1930, respectively.

MATERIALS AND METHODS

Desirable mother beets were selected from normal beets grown at Waseca, Minnesota, in 1930, 1931, and 1932. These were stored in sand during the winters at Waseca. The beets were planted in rows 3 feet 6 inches apart. In 1931, the beets were planted at Waseca May 8 and 9, at University Farm, St. Paul, May 7, and at Castle Danger, which is located 12 miles up the north shore of Lake Superior from Two Harbors, on May 18. Another planting was made at University Farm on May 15 for the purpose of studying the effect of aerating the isolators. In 1932 beets were planted at Waseca May 8; at University Farm April 28, May 10, and May 20; and at Castle Danger April 28 and May 11.

Beets were grown at Waseca and Castle Danger in 1933, but no results are given as the beets which were allowed to cross pollinate produced very little seed due to extreme heat and dry weather.

In order to determine whether beets responded differently to different isolators, many types were used. In 1931, 20 different types of parchment, kraft, cellophane,

pyralin, and black paper bags were used. In 1932, large, medium, and small bags of parchment, kraft, and cellophane were tested.

All parchment isolators were made of 30-pound weight parchment. The large parchment isolators used in 1931 were hand made, being 35 cm long, 15 cm wide, and 9 cm deep. The medium parchment isolators were of the type used in corn breeding at the University of Minnesota, being 30 cm long, 10 cm wide, and 6.5 cm deep. The small parchment isolators were the type of bags used for selfing rye, being 21 cm long and 6.5 cm wide.

The kraft grocery bags were of three sizes, the large ones being 34 cm long, 18 cm wide, and 11.5 cm deep. The medium kraft bags were 30 cm long, 15 cm wide, and 9 cm deep. The small kraft bags were 20 cm long, 10.5 cm wide, and 6 cm deep.

The large cellophane isolators used in 1931 were hand made, being 35 cm long, and 15 cm wide. The medium cellophane containers were hand made, being 25 cm long and 10 cm wide. In 1932, the cellophane isolators were made by folding and stapling the end of cellophane tubing. The large cellophane isolators were 12 cm wide and about 23 cm long. The medium cellophane isolators were 7.5 cm wide and about 23 cm long. The small cellophane isolators were 6.5 cm wide and about 21 cm long. The small cellophane isolators varied in thickness, the smallest bags being thinnest, and increased in weight to the heaviest.

All isolators were eyeletted at the top so that they could be tied to a bamboo or lath stake.

Either cotton or kapok was placed around the stems in 1931, before the isolators were firmly tied on at the base with heavy string. The kapok was somewhat more desirable because it did not mat when wet. In 1932 only kapok was used.

Isolators were placed on the branches a day or so before the lower glomerules on the branch opened. In beets the flowers, varying from 1 to 7, are formed in compact clusters known as glomerules.

At Waseca and University Farm in 1931 only the ends of the branches were clipped. This gave from one to several hundred glomerules per isolator. In addition, the plant sent out new branches under the isolator. It was observed at University Farm and Waseca that the branches in many of the isolators had grown so much and packed so tightly that mould grew and killed the portion of the plant under the isolator. As a result at Castle Danger in 1931, and at all locations in 1932, most of the branches were cut back to leave from 10 to 50 glomerules enclosed within the isolator. Some had as high as 100 glomerules, and a few with only the ends clipped were used to check the results obtained at University Farm and Waseca in 1931.

Part of the isolators with branches which had been cut back were removed as soon as the stigmas had shown signs of having been pollinated.

In 1932, 32 plants grown at Waseca and Castle Danger were covered with cloth tent isolators just before the first flowers opened. Finely woven cloth was used to form a tent about 65 cm square and 160 cm high. The tent was fitted tightly over four poles and a lath framework. Some of the tents were provided with small cellophane windows for observation.

The temperature under different isolators and of the outside air was taken at University Farm for 13 days after the isolators were put on the beets in 1932. The air and tent isolator temperatures were also taken at Waseca.

In 1931, it was observed that glomerules were larger on branches which were cut back. Accordingly, in 1932, two main branches of as nearly equal size and

vigor as possible were labeled with string. One of the branches was cut back similar to those which were put under the isolators.

In order to lower the temperature and humidity, air was pumped through some bags of the late planting. The bags were put on in the usual manner except that a 1/16-inch hose and a small glass tube, used to let the air in and out, were wrapped with kapok and the isolators tightly tied with string. The air current coming out of the glass tubing was strong enough to blow out a lighted match held 3 inches from the end.

The isolators and branches from which the isolators had been removed were harvested and allowed to dry in a building. After the branches were thoroughly dry the glomerules were rubbed off between two corrugated rubber mats. The glomerules without embryos were crushed or the glomerule disc fell out exposing the ovary cavity.

The glomerules resulting from selfing were planted at Waseca as a part of the regular sugar beet breeding program.

EXPERIMENTAL RESULTS

TYPES OF ISOLATORS

The relative value of different types of isolators as a means of insuring selfed glomerules is given in Table 1. This table is sub-divided into two main groups consisting, first, of isolators where the branches were cut back and opened after pollination; and second, where the branches were cut back and the bags remained closed until harvest.

TABLE 1.—*The effect of different types of isolators upon the production of selfed beet glomerules.*

Type of isolators	Size of isolator	Number isolators Used	Number isolators Setting glomerules	Percentage of isolators with glomerules	Average number glomerules per isolator with glomerules
Branches Cut Back and Opened After Pollination					
Castle Danger, 1931					
Parchment	Large	5	2	40.0	11.0
	Medium	20	12	60.0	38.6
	Small	7	6	85.7	14.3
Kraft	Large	10	9	90.0	32.7
	Medium	2	2	100.0	30.0
	Small	7	5	71.4	23.4
Cellophane	Large	5	4	80.0	29.8
	Medium	13	12	92.3	40.9
University Farm, 1932					
Parchment	Large	2	0	0	0
	Medium	104	23	22.1	10.3
	Small	89	32	36.0	7.3
Kraft	Large	28	9	32.1	14.4
	Medium	45	26	57.8	10.6
	Small	29	12	41.4	8.1
Cellophane	Large	3	0	0	0
	Medium	9	0	0	0
	Small	10	5	50.0	4.4

TABLE 1.—*Continued.*

Type of isolator	Size of isolator	Number isolators Used	Number isolators Setting glomerules	Percentage of isolators with glomerules	Average number glomerules per isolator with glomerules
		Branches Cut Back and Opened After Pollination			
		Waseca, 1932			
Parchment	Large	15	1	6.7	45.0
	Medium	149	50	29.8	9.5
	Small	2	1	50.0	2.0
Kraft	Large	68	38	55.9	16.1
	Medium	75	33	44.0	7.5
	Small	2	1	50.0	26.0
Cellophane	Large	1	0	0	0
	Medium	36	20	55.6	13.4
	Small	2	1	50.0	1.0
		Castle Danger, 1932			
Parchment	Large	64	9	14.1	6.9
	Medium	111	25	22.5	13.4
	Small	105	42	40.0	11.1
Kraft	Large	71	33	46.5	15.0
	Medium	70	34	48.6	13.1
	Small	9	5	55.6	15.6
Cellophane	Large	2	0	0	0
	Medium	25	12	48.0	6.7
	Small	42	19	45.2	11.4
		All Locations (4 station years)			
Parchment	Large	86	12	14.0	7.6
	Medium	441	110	24.9	13.7
	Small	203	81	39.9	9.7
Kraft	Large	184	95	51.6	17.8
	Medium	192	95	49.5	10.8
	Small	47	23	48.9	13.8
Cellophane	Large	6	0	0	0
	Medium	70	32	45.7	10.0
	Small	54	25	46.3	9.6
		Branches Cut Back, Bags Not Opened After Pollination			
		Castle Danger, 1931			
Parchment	Large	3	0	0	0
	Medium	34	4	11.2	12.0
	Small	10	1	10.0	1.0
Kraft	Large	20	11	55.0	16.1
	Medium	5	2	40.0	24.0
	Small	9	3	33.3	12.7
Cellophane	Large	8	4	50.0	20.2
	Medium	17	3	17.6	5.0

TABLE 1.—*Concluded.*

Type of isolator	Size of isolator	Number isolators		Percentage of isolators with glomerules	Average number glomerules per isolator with glomerules
		Used	Setting glomerules		
Branches Cut Back, Bags Not Opened After Pollination					
University Farm, 1932					
Parchment	Large	2	0	0	0
	Medium	161	12	7.5	12.6
	Small	194	20	10.3	8.3
Kraft	Large	57	4	7.0	14.0
	Medium	51	10	19.6	8.3
	Small	45	10	22.2	12.6
Cellophane	Large	1	0	0	0
	Medium	4	0	0	0
	Small	11	3	27.3	3.0
Waseca, 1932					
Parchment	Large	19	1	5.3	2.0
	Medium	96	3	3.2	32.0
	Small	8	0	0	0
Kraft	Large	8	2	25.0	7.0
	Medium	11	1	9.1	14.0
	Small	13	0	0	0
Cellophane	Large	6	0	0	0
	Medium	31	2	6.5	2.5
	Small	1	0	0	0
Castle Danger, 1932					
Parchment	Large	15	0	0	0
	Medium	108	1	.9	45.0
	Small	102	5	4.9	3.0
Kraft	Large	17	2	11.8	18.5
	Medium	37	0	0	0
	Small	8	1	12.5	14.0
Cellophane	Large	6	0	0	0
	Medium	21	0	0	0
	Small	36	0	0	0
All Locations (4 station years)					
Parchment	Large	39	1	2.6	2.0
	Medium	399	20	5.0	17.0
	Small	314	26	8.3	7.0
Kraft	Large	116	23	19.8	14.6
	Medium	104	13	12.5	11.2
	Small	75	14	18.7	12.7
Cellophane	Large	13	0	0	0
	Medium	56	2	3.6	2.5
	Small	48	3	6.3	3.0

Kraft was the most satisfactory isolating material when the branches were cut back and the isolators opened after pollination. No consistent differences were obtained between different sizes of kraft isolators. The large kraft bags were not as suitable as the medium or small sizes because they were bulky and hard to tie on the beet stems. The large sizes were more easily destroyed by the wind.

When the branches were cut back and the isolators opened after pollination, the small parchment isolators produced a higher percentage with glomerules than did the large or medium parchment isolators at each location. The medium parchment isolators were more desirable than the larger size.

The large cellophane isolators used in 1932, which were made of heavier material than the other sizes, were a total failure. In all cases the branches died without any indications of glomerule formation. The branches under small cellophane isolators appeared more vigorous than the branches under medium cellophane when the isolators were removed. The cellophane isolators were very unsatisfactory when they were not opened after pollination.

The differences between isolators of different sizes for all locations (4 station years) were analyzed statistically by using the four-fold contingency test as given by Fisher (9). The X^2 values are given in Table 2.

TABLE 2.—*Values of X^2 for different sizes of isolators when the isolators were opened and unopened.*

Size of isolators	Type of isolator		
	Parchment	Kraft	Cellophane
Isolators Opened			
Large and medium	4.886	.174	3.048
Medium amd small	14.909	.004	.004
Large and small	18.636	.109	3.099
Isolators Unopened			
Large and medium	.467	2.151	.554
Medium and small	3.109	1.294	.145
Large and small	1.605	.039	.020

The X^2 values for the 5 and 1% points with 1 degree of freedom are 3.841 and 6.635, respectively. When the isolators were opened after pollination (see Table 1), the medium-sized parchment gave 24.9% of the isolators with glomerules. This was statistically superior to the large-sized parchment which produced glomerules under 14.0% of the isolators. The small parchment bags with 39.9% of the isolators containing glomerules were statistically better than either the medium or large parchment isolators. No significant differences were obtained between the different sizes of kraft isolators.

When the isolators were unopened no statistically significant differences were obtained, although there were some indications that small parchment was more desirable than medium parchment.

The results from large, medium, and small isolators of each kind were combined and are given in Table 3.

TABLE 3.—*The effect of parchment, kraft, and cellophane as isolating materials.*

Material and treatment	Number isolators		Percentage of isolators with glomerules
	Used	Setting glomerules	
Isolators Opened After Pollination			
Parchment	730	203	27.8
Kraft	423	213	50.4
Cellophane	130	57	43.8
Isolators Unopened			
Parchment	652	47	7.2
Kraft	295	50	16.9
Cellophane	117	5	4.3

When the isolators were opened after pollination, 50.4% of the kraft, 43.8% of the cellophane, and 27.8% of the parchment isolators produced glomerules. The unopened isolators were much poorer since 16.9% of the kraft, 7.2% of the parchment, and only 4.3% of the cellophane isolators produced glomerules. The X^2 test for independence in a four-fold table was used to determine the relative value of different types of isolating materials. The data are given in Table 4.

TABLE 4.—*Value of X^2 for different types of isolating material when the bags were opened and unopened.*

Isolating material	Opened	Unopened
Parchment and kraft	59.032	23.341
Parchment and cellophane	13.457	.703
Kraft and cellophane	1.686	11.636

The kraft was significantly better isolating material than parchment whether the isolators were opened or not. The differences between cellophane and kraft were not significant when the isolators were opened, but highly significant when the isolators were unopened. The cellophane was more desirable than parchment when the isolators were opened but not different when the isolators were unopened.

Different sugar beet plants of commercial varieties are known to react very differently in their ability to set selfed seed. For this reason as many paired comparisons were made as possible of results when two types of isolators were used on the same plant. The data are given in Table 5.

In each comparison the kraft proved more satisfactory than parchment. The X^2 test was used to determine whether the differences were significant and an X^2 value of 25.985 was obtained. The relationship of kraft and parchment, when both isolators were on the same plant, is similar to that obtained when the isolators were on different plants.

TABLE 5.—*Comparisons of the percentage of the isolators containing selfed glomerules when kraft and parchment were on the same plant and when the isolators were opened after pollination.*

Place	Number comparisons	Isolators with glomerules			
		Kraft		Parchment	
		No.	%	No.	%
Castle Danger, 1931	10	9	90.0	5	50.0
University Farm, 1931	114	41	36.0	32	28.1
Waseca, 1931	140	76	54.3	49	35.0
Castle Danger, 1932	180	83	46.1	49	27.2
Total	444	209	47.1	135	30.4

Besides having more isolators with glomerules, kraft bags gave more glomerules per isolator than parchment. There were 78 comparisons on the same plant where glomerules were produced under kraft and parchment isolators. The kraft averaged 17.05 glomerules per isolator and the parchment 11.54 glomerules per isolator. The mean difference of 5.51 glomerules was statistically significant when analyzed by Student's method as applied to paired comparisons. The Z value was .627.

Kraft was the most desirable isolating material probably because of lower humidity and temperature within the isolator. The humidity within the pyralin isolators was very high. One could always find the kapok at the base of the isolator wet and drops of water on the inside. The moisture weakened the pyralin isolators causing them to break and nearly all were lost. The air within the large cellophane isolators, which were made of heavier material than the medium and light cellophane types, was also very humid. Moisture could be noticed occasionally inside the parchment isolators. The kraft isolators absorbed water readily during a rain and it may be assumed that they lost moisture from within as readily.

To study the humidity relationships within the isolators at University Farm, air was forced into different types, thus reducing humidity to the same level within the different isolators.

Seed production was very low in 1931 as too many glomerules were enclosed in each isolator. The ends of the branches were clipped in the same manner as used in the regular selfing plats. Only 10 of 64 isolators, or 15.6% of the isolators, contained glomerules. While this was not a good set of glomerules, it compared favorably with the regular selfing plat isolators which yielded only 1.7% of the isolators with glomerules.

Eight of the 14 plants used on the air line set some glomerules. This was 57.1% of the plants with glomerules under isolators. In the check plat, 4.1% of the plants produced glomerules under isolators.

The plants used in 1932 did not have nearly as many main stems arising from the crowns as the early and medium plantings in the regular selfing plat. The branches were cut back and only 10 to 50 glomerules were enclosed in each isolator.

Twenty-nine of the 58 isolators, or 50%, on the air line, when the isolators were removed after pollination, contained glomerules. The five plants on this same plat which received no air failed to produce glomerules. Glomerule production on the air line was somewhat higher than the results obtained in the regular plat studies in which 33.9% of the opened isolators formed glomerules.

In the regular plats, planted on April 29 and May 10, respectively, average yields of seed per plant were 103 grams and 72 grams. The plants used on the air line were planted on May 20 and gave an average seed production of 65 grams per plant.

Of the 12 plants used on the air line, 9 set glomerules under isolators. This number was equal to 75%, while 51% set glomerules in the regular selfing plat.

TEMPERATURE WITHIN ISOLATORS

The temperatures within 23 isolators of three different types were obtained at University Farm in 1932. The bulbs of the thermometers were held away from the plant and the sides of the isolator by the kapok which was around the stem of the plant and thermometer The temperatures were recorded at 8:00 a.m., 1:00 p.m., and 5:00 p.m.

The isolators were placed on the tallest branches so as to prevent shading. The average temperatures in degrees Fahrenheit for 13 days after the isolators were placed on the plants were for kraft 74.7°, 82.7° and 81.0°; for parchment 73.3°, 83.7°, and 82.0°; for cellophane 81.8°, 88.5°, and 84.3°; and open air 71.0°, 79.1°, and 77.8° at 8:00 a.m., 1:00 p.m., and 5:00 p.m., respectively.

The significance of differences under different types of isolators was analyzed by the analysis of variance. The mean squares are given in Table 6.

TABLE 6.—*The mean squares for the temperatures under different types of isolators at 8:00 a.m., 1:00 p.m., and 5:00 p.m.*

Variability for	Degrees freedom	8:00 a.m.	1:00 p.m.	5:00 p.m.
Types of isolators	2	2,070.73	923.01	268.17
Within isolators:	22	195.00	25.92	71.70
Parchment	9	110.05	26.35	66.44
Kraft	7	188.87	13.12	54.76
Cellophane	6	329.59	40.22	99.26

Much variation was found between isolators of the same material. This variation was greatest at the 8:00 a.m. and smallest at the 1:00 p.m. readings. The variation between isolators of the same material is explained by the probable fact that if the sun shone on a flat side of the isolator it would warm up more rapidly than if it shone on a narrow side. At 1:00 p.m. when the sun shone more directly down on the isolators much less variation was obtained.

The types of isolators were very different in the light of the mean square for types of isolators divided by the mean for average variability within isolators. The cellophane isolators gave an average

temperature much higher than the kraft or parchment. The parchment isolators averaged 1 degree higher than kraft at 1:00 p.m. and 5:00 p.m.

TENT ISOLATORS

Tent isolators similar to those used by Munerati (12) and Archimovitch (3) were tried at Castle Danger and Waseca in 1932. The beets used in this study were isolated from the regular selfing plats. All of the beets were covered with tents. Individual plants were tented just before the first flowers opened. Of the 18 plants grown at Castle Danger, 7 set from 0.5 to 12 grams per plant, that is, 38.9% of the plants under tents set glomerules. This was almost identical with the results obtained at Castle Danger when the isolators were placed on the plants. At Waseca, 6 of the 14 plants under tents set glomerules. This was a percentage of 42.9 as contrasted with 51 when branch isolators were used. Seed setting under tents was much lower than reported by Archimovitch (3) who obtained glomerules on 72 to 90% of the plants placed under tent isolators.

The glomerules under the tents were very small, and in most cases each glomerule possessed but one small embryo. The stems of the plants were long, slender, and lacking in vigor. The plants developed very few new leaves.

The temperatures under the tents at Castle Danger at 8:00 a.m., 1:00 p.m., and 5:00 p.m. for the first 3 days after the plants were tented were 78.0°, 77.3°, and 75.7° F, respectively. At the same hours the temperatures of the atmosphere outside the tents were 66.5°, 69.3°, and 69.7°, respectively. The average temperatures under the tents at Waseca for 22 days after the tenting were 85.6° and 94.3° for 8:00 a.m., and 1:00 p.m., respectively. At the same hours the temperatures of the atmosphere outside of the tents was 81.3° and 89.8°, respectively. The humidity inside of the tents was high. The top of the soil in the tents at Castle Danger was wet and covered with algae.

EFFECT OF OPENING ISOLATORS AFTER POLLINATION

When the branches were cut back leaving 10 to 50 glomerules per isolator, the stigmas on all the flowers died within 10 to 20 days. The isolators could then be removed without danger of cross-pollination. If the branches are not cut back, the isolators cannot be removed because the glomerules flower progressively up the spike.

The effect of opening different types of isolators after pollination is given in Table 7.

In all cases there were substantial increases in percentage of isolators with glomerules when the isolators were opened after pollination. The increases were largest at Waseca and Castle Danger in 1932 when very few unopened isolators produced glomerules. The unopened parchment, kraft, and cellophane isolators at Waseca produced 3.3, 9.4, and 5.2%, respectively, of the isolators with glomerules compared with 31.3, 49.7, and 53.8%, respectively, of the opened isolators with glomerules. At Castle Danger, all 63 unopened cellophane isolators failed to produce seed, while 31 out of 69 opened cellophane isolators

TABLE 7.—*The effect of opening isolators of different types after pollination (branches cut back).*

Kind of isolators	Treatment	No. of isolators	Isolators with selfed glomerules	Percentage of isolators with selfed glomerules	Number glomerules per isolator with glomerules	Average number glomerules per isolator
			Castle Danger, 1931			
Parchment	Unopened	63	9	14.3	12.8	1.8
	Opened	38	23	60.5	29.0	17.6
Kraft	Unopened	63	26	41.3	19.2	7.9
	Opened	30	26	86.7	32.1	27.8
Cellophane	Unopened	55	15	27.3	25.0	6.8
	Opened	19	16	84.2	38.1	32.1
			University Farm, 1932			
Parchment	Unopened	358	39	10.8	9.6	1.05
	Opened	195	55	28.2	8.6	2.42
Kraft	Unopened	153	24	15.7	11.0	1.83
	Opened	102	47	46.1	10.7	4.93
Cellophane	Unopened	18	3	16.7	3.0	0.5
	Opened	19	5	26.3	4.4	1.16
			Waseca, 1932			
Parchment	Unopened	123	4	3.3	24.5	0.80
	Opened	166	52	31.3	10.0	3.14
Kraft	Unopened	32	3	9.4	9.3	0.88
	Opened	145	72	49.7	12.3	6.09
Cellophane	Unopened	38	2	5.2	2.5	0.13
	Opened	39	21	53.8	12.8	6.90
			Castle Danger, 1932			
Parchment	Unopened	225	6	2.7	10.0	0.27
	Opened	280	76	27.1	11.4	3.08
Kraft	Unopened	62	3	4.8	17.0	0.82
	Opened	150	72	48.0	14.2	6.79
Cellophane	Unopened	63	0	0	0	0
	Opened	69	31	44.9	9.6	4.30

produced glomerules. In 1931, at Castle Danger, a fair set of glomerules was obtained when the isolators were unopened, but the percentage of isolators with glomerules was more than doubled when the isolators were opened after pollination.

The number of isolators producing glomerules for opened and unopened bags was compared for different isolating materials and X^2 was used to determine whether the differences were significant (Table 8).

TABLE 8.—*X^2 values to determine if there is a significant difference as a result of opening bags on the numbers of plants setting glomerules.*

Place	Isolating material		
	Parchment	Kraft	Cellophane
Castle Danger, 1931	23.415	16.991	18.807
University Farm, 1932	26.814	28.137	.507
Waseca, 1932	35.641	17.419	21.686
Castle Danger, 1932	54.950	35.746	35.566

All of the X^2 values are highly significant except with cellophane at University Farm where only 39 isolators were used. This proves it was a very desirable practice, under these conditions, to remove the isolators after pollination. It provides embryos which have been fertilized with a better opportunity to develop.

EFFECT OF CUTTING BACK

Plants with isolators.—It was observed at University Farm and Waseca in 1931 that many of the isolators where only the ends of the branches were clipped were broken because there was not enough room for the plants to grow. Other branches were killed because of moisture and subsequent mold growth. Accordingly, at Castle Danger in 1931 and at all locations in 1932, most of the branches were cut back leaving 10 to 50 glomerules per isolator.

When the ends of the branches were clipped, 4 isolators out of 233 produced 19 glomerules at University Farm in 1931, 19 out of 254 produced 77 glomerules at Waseca in 1931, 1 out of 72 produced 50 glomerules at University Farm in 1932, and 47 isolators produced no glomerules at Castle Danger in 1932. On an average when the branches were cut back 10.6% of the isolators produced glomerules.

Open-pollinated plants.—To determine the effects of cutting back branches on open-pollinated beets, two branches as nearly alike as possible on the same plant were marked with string and one of the branches was pruned in the same manner as those previously described that were placed within isolators. The seed of the pruned branch and of an equal length on the untrimmed branch was harvested when the glomerules were mature. After the glomerules had thoroughly air dried, they were weighed on an analytical balance. At University Farm there were 34 pairs harvested. The mean weight per glomerule on the branches cut back was 52.43 milligrams, while the mean weight per glomerule on branches not cut back was only 34.90 milligrams. This gave an average increase of 17.53 milligrams per glomerule as a result of pruning the branch.

The cut back spikes and those not cut back were taken as a pair and the weight of glomerules produced was statistically analyzed by the analysis of variance as outlined by Fisher (9). Variance due to treatment divided by variance due to error was 162.62, a very significant result. The F value of 1% as given by Snedecor (20) for N_1 of 1 and N_2 of 30 is 7.56. The variation between plants was also significantly different, variance due to plants divided by error being 6.61. The F value of 1% for N_1 of 24 and N_2 of 30 was 2.47.

The effect of cutting back the branches on the production of open-pollinated glomerules for 35 pairs at Castle Danger in 1932 were very similar to those obtained at University Farm. The mean weight per glomerule on branches cut back was 64.65 milligrams, while the mean weight per glomerule on branches not cut back was only 45.62 milligrams, or an average increase of 19.03 milligrams per glomerule as a result of cutting back the branches.

Plants and treatment were highly significant. The variance due to plants divided by variance due to error was 5.66. The variance due to treatment divided by variance due to error was 119.54.

EFFECT OF LOCATION

The difference between locations was studied as the beets were selected from the same field each year. The summary for all locations is given in Table 9.

The best set of glomerules was obtained at Castle Danger in 1931 and the poorest at Castle Danger in 1932. The beets were on the same type of soil and located about the same distance from Lake Superior. The mean maximum temperature for the first 20 days after isolating was 68.3° and 74.7°F for 1931 and 1932, respectively. The higher temperature would increase the humidity of the atmosphere especially near the lake.

The X^2 test was used to determine whether glomerule formation was significantly different at the three locations and calculated values are given in Table 10.

In 1931, the production of selfed glomerules at Castle Danger was definitely superior to that at Waseca or at University Farm and also far superior to that at Castle Danger in 1932. In fact, in 1932, on the unopened isolators, more desirable results were obtained at University Farm than at Castle Danger. Temperatures at Castle Danger in 1932 were much higher than in 1931, as has been previously mentioned. These results make it appear very probable that cooler temperatures are desirable if high production of selfed seed is desired. While the data are not very conclusive they form a good basis for the conclusion that Castle Danger would usually be a more satisfactory location for the production of selfed seed of beets than either University Farm or Waseca.

SUMMARY

Tent isolators and isolators of different types and sizes of parchment, kraft, and cellophane were placed on mother beets grown at University Farm, Waseca, and Castle Danger, Minnesota.

When branches were cut back, leaving 10 to 30 glomerules per isolator and the isolator opened after all of the flowers had been pollinated, a satisfactory production of seed resulted. When the isolators were not opened after pollination much less seed was obtained. The branches isolated when only the ends were clipped produced practically no seed and most of the branches were killed or the isolators were broken.

Kraft isolators, whether opened or unopened, were more satisfactory for seed formation than parchment or cellophane.

TABLE 9.—*Summary of the number of isolators and percentage with selfed glomerules for different treatments, University Farm, Waseca, and Castle Danger, 1931 and 1932.*

Place	Year	Treatment	Number isolators	Isolators with selfed glomerules	Percentage of isolators with selfed glomerules	Number glomerules per isolator with glomerules	Av. number glomerules per isolator
University Farm......	1931	End clipped unopened	233	4	1.7	4.8	0.08
Waseca..............	1931	End clipped unopened	254	19	7.5	3.7	0.28
Castle Danger........	1931	End cut back unopened	232	54	23.3	18.7	4.35
		End cut back opened	111	76	68.5	34.4	23.59
Waseca..............	1932	End cut back unopened	193	9	4.7	14.6	0.68
		End cut back opened	350	145	41.4	11.5	4.78
University Farm......	1932	End clipped unopened	72	1	1.4	50.0	0.69
		End cut back unopened	529	66	12.5	9.8	1.23
		End cut back opened	316	107	33.9	9.3	3.15
Castle Danger........	1932	End clipped unopened	47	0	0	0	0
		End cut back unopened	350	9	2.6	12.3	0.32
		End cut back opened	499	179	35.9	12.2	4.37
All locations and years		Ends clipped unopened	606	24	4.0	5.8	0.23
		Ends cut back unopened	1,304	138	10.6	13.8	1.46
		Ends cut back opened	1,276	507	39.7	14.7	5.85

TABLE 10.—*The value of X^2 for glomerule formation at the different locations when the isolators were opened and not opened after pollination.*

Locations	Isolators	
	Opened	Unopened
Castle Danger 1931 and University Farm 1932	40.174	14.159
Castle Danger 1931 and Waseca 1932	24.689	28.907
Castle Danger 1931 and Castle Danger 1932	39.658	61.958
University Farm 1932 and Waseca 1932	4.044	9.273
University Farm 1932 and Castle Danger 1932	.344	26.479
Waseca 1932 and Castle Danger 1932	2.692	1.698

X^2 for 5% 3.841; for 1% 6.635.

Tent isolators were not as satisfactory as branch isolators. The seeds obtained were very small. Temperature and humidity within the tents were very high and as a result the plants were weakened after being placed in tents.

Mother beets which were planted early were more satisfactory than later plantings when branch isolators were used. Early planted beets flowered when the temperature was cooler and produced many main branches arising from the crown.

When uncovered branches were cut back, the glomerules produced on them were larger than those obtained from similar branches not cut back. Cutting back the branches also permitted the removal of isolators after having been on the plants 2 to 3 weeks.

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THE NITROGEN, PHOSPHORUS, AND CALCIUM CONTENT OF THE COTTON PLANT AT PRE-BLOOMING TO EARLY BOLL STAGES OF GROWTH[1]

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DURING the season of 1933 a great deal of interest was manifested by farmers and others relative to the comparative composition of the cotton plant with other crops which are commonly used as feed for livestock. This was occasioned by the cotton acreage reduction program. The program became effective in central Oklahoma when the cotton plant was in the pre-bloom to early boll stages of development. Certain articles appeared at that time in farm papers relative to the feeding qualities of the plant. It is not the purpose of the writer to discuss this side of the question (1, 2, 7)[3], although observations would indicate that to be of much value in this respect the plant would have to be converted into silage, because of loss of leaves in curing, lack of palatability of the dried stalks, etc., but to present some data on the nitrogen, phosphorus, and calcium content of the plant at these stages of growth and on the boll growth at later stages of development.

Holley, *et al.* (3) present data on the composition of the stems, leaves, and roots of cotton grown in culture solutions at approximately the stages of growth reported here. The general results for the N, P and Ca in the leaves and stems were of the same order of magnitude as found by the writer. Fraps (1) reports some rather extensive data on the mature cotton plant and its various parts. McHargue (7) has given data on the usual chemical composition of this plant along with elements such as Cu, Fe, Mn, Zn, and Na which are not so commonly reported.

White (9, 10) concluded that the cotton plant takes from the soil 34, 37, and 33% of its N, P, and Ca, respectively, from the time the seed sprouts until the first square is produced. During the period of growth of the first square to the first bloom it absorbs 32, 40, and 41% of its N, P, and Ca, respectively. From this period until the first open boll appears the percentages are 18, 18, and 10, respectively; and from here to maturity 16, 5, and 16%, respectively, are obtained for these three elements. Data are also given for the absorption of sulfur, potassium, and magnesium.

Hutchinson and Patterson (4) studied the composition of the cotton plant at various stages of development and report data on the roots, stems, leaves, and bolls of this plant. The need of the cotton plant for phosphoric acid, potash, lime, and magnesia is stressed by these workers, who further state that doubtless the proportion of available potash and phosphoric acid to available nitrogen in the soil should be large for proper fruit formation.

Kudrin (5) studied the composition of the cotton plant at five different stages of growth and observed that it absorbed the largest amount of nutrients from the soil between the bud (square) formation and bloom formation stages. He stated

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[3]Figures in parenthesis refer to "Literature Cited", p. 57.

further that at this time there was an increased absorption of Ca and N compared with P_2O_5 and Mg.

PROCEDURE AND DATA

On July 28, 1933, ten different fields of cotton on the Oklahoma Agricultural Experiment Station farm were sampled. Each sample consisted of two or three representative stalks taken from a small area in each location where the stand was uniform. The usual spacing was 10 to 12 inches in the row with rows 3.5 feet apart. Each of the stalks was separated into stem, leaves, and bolls and analyses were made on each separate division. No large bolls occurred on any of the stalks, although in case of locations 5 and 10, many small bolls appeared along with bolls approximately one-third developed. Squares of various sizes appeared on all stalks. The plants in locations 1, 2, 3, and 8 held only small squares, while those in locations 4 and 8 had larger squares as well. Plants 6b and 9b also carried large as well as small squares. The squares were included with the leaves in making the analyses. The green weight of each plant and its constituent parts were recorded immediately upon collection. Each sample was dried at 105° C for 48 hours, after which it was ground to pass through a 0.5-mm sieve. The analyses were made according to the A. O. A. C. methods, the regular Kjeldahl procedure without modification being used for total nitrogen.These data are presented in Tables 1 and 2.

For boll development, stalks were selected during the month of August, 1933, on which each stalk carried all of the various stages of boll development studied. The bracts were removed in preparing these samples for analysis. The results are given on the basis of oven-dry weight and are presented in Table 3 and 4.

DISCUSSION AND SUMMARY

No data are presented for the root system of the plant, but from the composition of the leaves, stem, and bolls it appears that there must be a rather pronounced intake of phosphorus by the plant as the squares develop and bolls are formed. While the average data show a slight decrease in the percentage of phosphorus found in the stems and in the leaves with plants having bolls over those not having bolls, the difference is small and is probably not significant in the cases presented. There can be no doubt, however, as to the decrease in the percentage of the plant's total phosphorus found in the leaves when the plant is developing bolls. This appears to be due to the increase in total weight of the plant by boll growth with only a rather limited withdrawal from the leaves. Since cotton may have newly formed squares to open bolls on the same plant at the same time, there must be present in the soil during this rather lengthy square and boll development period of the plant considerable available phosphorus. This explains, partially at least, why the more available phosphate fertilizers usually give best results with this crop.

Very much the same may be said of nitrogen, though the decrease in percentage of nitrogen in the leaves as bolls are forming is more than that for phosphorus. The type of nitrogen fertilizer to use would depend on the time of application. The usual practice of side dressing

TABLE 1.—*Composition of the cotton plant at pre-blooming to early boll stages of growth.*

Location	Plant	Percentage of nitrogen in					Percentage of calcium in					Percentage of phosphorus in				
		Leaves	Stems	Bolls	Whole plant, dry wt.	Whole plant, gr. wt.	Leaves	Stems	Bolls	Whole plant, dry wt.	Whole plant, gr. wt.	Leaves	Stems	Bolls	Whole plant, dry wt.	Whole plant, gr. wt.
1	a	3.80	1.33	—	3.037	0.831	3.39	0.75	—	2.571	0.703	0.286	0.115	—	0.233	0.064
	b	3.62	1.31	—	2.850	0.668	3.58	0.69	—	2.615	0.613	0.235	0.125	—	0.198	0.047
	c	3.62	1.15	—	2.910	0.583	3.91	0.51	—	2.939	0.588	0.230	0.101	—	0.193	0.039
2	a	3.66	1.35	—	2.890	0.652	3.59	0.76	—	2.640	0.595	0.267	0.159	—	0.231	0.052
	b	4.00	1.49	—	2.996	0.559	3.62	0.86	—	2.510	0.468	0.286	0.156	—	0.234	0.044
3	a	3.75	1.54	—	3.308	0.745	3.59	0.73	—	3.018	0.680	0.237	0.165	—	0.227	0.050
	b	3.81	1.45	—	2.023	0.593	3.70	0.83	—	2.738	0.537	0.238	0.165	—	0.214	0.042
4	a	3.41	1.14	—	2.843	0.569	3.59	0.47	—	2.809	0.562	0.273	0.098	—	0.229	0.046
	b	3.75	1.21	—	2.939	0.548	3.72	0.57	—	2.708	0.505	0.291	0.128	—	0.239	0.045
5	a	3.36	1.29	2.14	2.740	0.539	4.37	0.96	0.40	2.719	0.535	0.264	0.141	0.330	0.272	0.053
	b	3.75	1.32	2.37	2.975	0.526	4.48	1.11	0.34	2.780	0.492	0.286	0.144	0.336	0.277	0.049
6	a	3.44	1.05	3.03	2.690	0.564	3.80	0.85	0.41	2.509	0.472	0.236	0.123	0.162†	0.198	0.037
	b	3.59	1.44	—	2.904	0.614	4.00	0.76	—	2.969	0.628	0.216	0.126	—	0.187	0.040
7	a	3.66	1.65	—	2.810	0.526	3.52	0.97	—	2.439	0.456	0.235	0.159	—	0.203	0.038
	b	3.72	1.11	—	3.318	0.799	3.64	0.61	—	3.174	0.764	0.232	0.134	—	0.217	0.052
8	a	3.82	1.27	—	3.069	0.705	3.32	0.61	—	2.770	0.636	0.290	0.141	—	0.246	0.057
	b	3.82	1.37	—	3.394	0.710	3.46	0.57	—	2.957	0.618	0.259	0.113	—	0.234	0.049
9	a	3.09	1.46	2.27	2.641	0.611	3.42	0.64	0.15†	2.373	0.549	0.175	0.070	0.095†	0.142	0.033
	b	3.44	1.21	—	2.816	0.568	2.99	0.59	—	2.317	0.467	0.218	0.061	—	0.174	0.035
10*	a	2.75	0.84	2.06	2.114	0.412	4.22	0.54	0.29	2.171	0.423	0.224	0.064	0.201	0.182	0.035
	b	3.42	1.37	2.01	2.623	0.546	4.19	0.77	0.25	2.441	0.508	0.196	0.107	0.187	0.175	0.037
General Av. . .		3.58	1.30	2.31	2.882	0.609	3.72	0.72	0.31	2.675	0.562	0.246	0.123	0.218	0.214	0.045
Av. plants without bolls		3.70	1.33		3.007	0.615	3.57	0.69		2.745	0.588	0.253	0.130		0.217	0.047
Av. plants with bolls. . . .		3.03	1.22	2.31	2.631	0.533	4.05	0.81	0.31	2.499	0.497	0.230	0.108	0.218	0.208	0.041

*Location 10 bottom land soil; all others upland soil.
†Probably not accurate on account of extremely small sample. See also Table 3 where large samples were available.

TABLE 2.—*Ratio studies concerning leaves, stems, and bolls.*

Location	Plant	Percentage of total content in the leaves			Weight of dry matter, grams		
		N	P	Ca	Leaves	Stems	Bolls
1	a	86.46	84.95	91.04	19.0	8.5	0
	b	84.68	78.99	91.25	25.0	12.5	0
	c	88.77	85.06	95.03	10.0	4.0	0
2	a	84.43	77.05	90.40	23.0	11.5	0
	b	80.11	73.33	86.28	15.0	10.0	0
3	a	90.69	85.18	95.16	20.0	5.0	0
	b	84.01	74.26	89.86	14.0	7.0	0
4	a	89.97	89.31	95.84	15.0	5.0	0
	b	86.86	82.91	93.28	16.0	7.5	0
5	a	69.74	55.28	91.43	31.0	6.0	17.5
	b	70.59	57.76	83.04	28.0	8.0	14.0
6	a	74.59	69.55	88.11	14.0	7.0	3.0
	b	84.28	78.60	91.87	15.0	7.0	0
7	a	75.15	66.83	83.26	7.5	5.5	0
	b	94.85	90.50	97.02	11.0	2.0	0
8	a	87.88	83.15	84.35	12.0	5.0	0
	b	92.98	91.59	96.65	19.0	4.0	0
9	a	76.05	80.11	93.67	13.0	4.0	3.0
	b	87.97	90.17	92.93	9.0	3.5	0
10	a	55.25	57.25	85.26	42.5	20.0	29.0
	b	68.94	59.15	90.74	46.0	18.0	23.0
General av.		81.63	76.71	90.78			
Av. plants without bolls		86.61	82.12	91.61			
Av. plants with bolls		69.19	63.18	88.71			

TABLE 3.—*A summary of the analyses of cotton bolls at various stages of development.*

Stage of growth	N %	P %	Ca %
Practically mature bolls	2.40	0.223	0.271
¾ mature bolls	2.64	0.268	0.284
½ mature bolls	2.56	0.249	0.326
¼ mature bolls	2.82	0.306	0.598
⅛ mature bolls	3.57	0.390	1.255
Bloom*	3.69	0.448	1.200
Pre-bloom†	4.56	0.533	1.568

*Includes the blossom but not the bracts.
†Includes only the bud without bracts.

with such available forms as nitrate of soda after chopping or the application of mixed fertilizers containing various types of nitrogen

TABLE 4.—*A summary of the analyses of the burr and the lint and seed.*

Stage of growth	N %	P %	Ca %
Burrs			
Practically mature (bolls not open)	1.98	0.115	0.359
¾ mature	2.34	0.150	0.449
½ mature	2.60	0.179	0.607
¼ mature	2.60	0.245	0.742
⅛ mature	3.42	0.357	1.580
Seed and Lint			
From practically mature bolls	2.04	0.248	0.188
From ¾ mature bolls	1.98	0.272	0.159
From ½ mature bolls	2.57	0.278	0.194
From ¼ mature bolls	2.51	0.269	0.179
From ⅛ mature bolls	3.73	0.415	0.201

carriers at or near planting time, would appear to be confirmed as being good practices on soils not capable of supplying the necessary plant food from the standpoint of intake or need of this plant food element by the cotton plant during the square development-boll formation period of growth. If boll weevil infestation occurs, bolls may not be formed or developed. Where this is the case the heavy nitrogen consumption that ordinarily goes into the bolls is utilized by the plant to produce excessive vegetative growth.

The calcium content of the leaves appears to increase some as squares and bolls are produced by the plant. The increase is not quite sufficient to maintain the percentage composition for the whole plant when the bolls are making rapid growth since the bolls are relatively low in this element soon after they develop any appreciable size. However, since the percentage of calcium is maintained or increased by the leaves and stems of the plant during this period of rapid vegetative growth, the intake of calcium is considerable at this time and is accounted for in the increased vegetative growth and that present in the bolls. The seed and lint taken together are relatively low in calcium compared with that in the burr. The results secured by the writer for the nearly mature unopen burrs are lower than those secured by Fraps (1) and some other workers (6, 8) for mature open burrs.

Summarizing, it appears that there is a considerable absorption of calcium by the cotton plant at this period of development, but that most of it is concerned with the vegetative part of the plant remaining in the leaves and stems. The intake of nitrogen and phosphorus is also great at this time, and while a considerable amount of each is required for the rather extensive vegetative growth taking place, boll development accounts for a large proportion of the nitrogen and phosphorus in the mature plant.

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LENGTH OF EXPOSURE TO LIGHT IN RELATION TO PLANT GROWTH IN RICE[1]

CHIEN-LIANG PAN[2]

MANY studies have been made with different crops on length of exposure to light in relation to time of maturity. Garner and Allard (4)[3] first introduced the term "photoperiodism" to designate the response of plants to the relative length of day and night. He classified crop plants into two groups, namely, long-day types which respond to long days and short-day types which blossom normally in the short-day season. Tincker (9) found by exposing plants of soybeans, chrysanthemums, and runner beans to light less than the normal length of day that flowering was accelerated. On the other hand, the flowering period of red clover, Gramineae, and radish was retarded. Garner (5) found with plants that responded to a long day that a 6-hour alternation of light and darkness hastened the appearance of blossoms. In the short-day varieties of soybeans, flowering was decidedly delayed by 6-hour and 4-hour alternations. Garner (3) reported that Biloxi soybeans blossomed in 26 days when they were allowed to receive 7 hours of light daily, while plants of the same variety exposed to light throughout the day required 110 days to flower. Similar results were obtained from wild asters, lima beans, the Peking soybean, and the common ragweed. Evans (2) reported that timothy growing at Savannah, Georgia, bloomed much later than when it was grown at Fairbanks, Alaska. This was due to the fact that the length of day is gradually increased from south to north during the time just a short period after spring growth.

Harrington (6) reported that in wheat, barley, oats, and rye varying intensities of light gave the same effect on plant growth as a modification in duration of light. The stronger the intensity of light, the fewer the days required from seeding to heading. Moderate intensity of light was needed in order to produce a crop with tall plants. Shirley (8) reported that with decreasing light intensity buckwheat, sunflower, geum, redwood, and galinsoga tended to increase their height, but all plants flowered approximately at the same time under all light intensities. Garner and Allard (4) found that, although the length of daily exposure to light may exert a controlling influence on the attainment of the reproductive stage, light intensity is not a factor of importance. Adams (1) found that the rate of growth was more rapid at first in the plants exposed to a diminished supply of light, but plants constantly exposed to light for a greater number of hours ultimately attained the greater height.

[1]Contribution from the Department of Crop Breeding of the Provincial Experimental Station, Chekiang, China. Paper read at the annual meeting of the American Society of Agronomy, Chicago, Ill., December 6, 1935. Received for publication November 25, 1935.

[2]Formerly Junior Agronomist. The author wishes to express his deep appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, and to Dr. H. K. Wilson, Associate Professor of Agronomy, University of Minnesota, for advice regarding the interpretation of data and preparation of this manuscript.

[3]Numbers in parenthesis refer to "Literature Cited", p. 63.

Electrical illumination in the case of hemp had a retarding effect on both the height and weight of the plants. Flowering of soybeans was entirely prevented by continuous exposure to light in the day time followed by 5 hours of electrical illumination in the night. Ramaley (7) reported that increasing the length of day by using artificial light accelerated the blossoming period of eight species of Caryophyllaceous and some species of Agrostemma, Dianthus, and Viscaria. Rice has not been extensively studied, the present paper summarizing a preliminary experiment.

MATERIALS AND METHODS

The material used in this study consisted of six varieties of rice with different growing periods when grown under natural conditions. Ten seeds of each variety were sown per pot on April 19, 1932, and thinned to five plants per pot 10 days after germination. None of the treatments was replicated.

The length of period that the plants were exposed to light was artificially controlled. On account of lack of equipment, the use of artificial light in order to lengthen the period of exposure was not studied, but the normal light period was shortened by covering the pots with a black cloth cover. The different treatments made are described as follows:

Treatment A, Check trials, growing plants under normal conditions.

Treatment B, Covering the pots at 6 p.m. to 6 a.m., the next morning exposing the plants to light for 12 hours per day.

Treatment C, Exposing the plants to light from 8 a.m. to 5 p.m., making a period of 9 hours.

Treatment D, Exposing the plants for 6 hours from 9 a.m. to 3 p.m.

The treatments mentioned were started on June 15. Number of culms per pot was recorded. The tallest plant in each pot was measured. The date of heading was studied by counting the number of heads on and after the day on which the first head was produced.

EXPERIMENTAL DATA

NUMBER OF CULMS PER PLANT

Table 1 shows that the early and medium maturing varieties, as 1781, 2407, 4461, and 3921, produced fewer culms when grown under

TABLE 1.—*The effect of length of exposure upon the number of culms produced per plant.*

Varieties	Treatments							
	A (check)*		B (12 hrs.)		C (9 hrs.)		D (6 hrs.)	
	No.	%	No.	%	No.	%	No.	%
1781 (E)†......	47	100	32	68.08	32	68.08	24	51.06
2407 (E).......	39	100	31	79.49	33	84.62	28	71.79
4461 (M).......	26	100	22	84.62	14	53.85	20	76.92
3921 (M).......	37	100	23	62.16	22	59.46	23	62.16
9549 (L)........	18	100	22	122.22	19	105.56	21	116.67
9554 (L).......	20	100	22	110.00	20	100.00	24	120.00

*Considering the check pot as 100%.
†EML are the letters used to designate early, medium, and late maturing rice.

short-day treatments than the plants of the same varieties when grown under natural conditions. In the case of late-maturing varieties, the plants treated by reducing the length of light showed a slight increase in number of culms, although the difference may be within the limits of experimental error.

The results with the early- and medium-maturing varieties may be expected because shortening the period of exposure naturally reduces plant growth; as a result, the stooling ability of the plants probably was decreased.

It is difficult to explain the results obtained with the late-maturing varieties. Speculation of any sort is unwarranted before further confirmation is obtained.

HEIGHT OF PLANT

Five plants were grown per pot. The height of each plant was measured from the soil surface to the top of the plant, the measurement being made in centimeters. The average of these five measurements was considered as the average height of these five plants for the treatment under which they were grown. The results are given in Table 2.

TABLE 2.—*The effect of length of exposure on the height of plant.*

Variety	Treatments							
	Check*		12 hours		9 hours		6 hours	
	Height, cm	%	Height, cm	%	Height, cm	%	Height, cm	%
1781.......	82.4	100.00	83.7	101.58	97.0	117.72	90.0	109.22
2407.......	84.0	100.00	82.9	98.69	90.9	108.21	83.0	98.81
4461.......	85.9	100.00	98.1	114.20	94.7	110.24	96.4	112.22
3921.......	66.9	100.00	91.4	136.62	86.0	128.55	89.1	133.18
9549	71.8	100.00	76.5	106.54	74.9	104.32	72.9	101.53
9554.......	65.6	100.00	70.6	107.62	71.1	108.38	74.9	114.18
Av......	76.1	100.00	83.9	110.25	85.8	112.75	84.4	110.91

*Check considered as 100.

As an average of six varieties, the plants exposed 12 hours were about 10% taller than the check plants, but no significant difference was obtained between plants grown under 6, 9, and 12 hours of exposure to light treatments. The data clearly indicate that reducing the length of exposure increased the height of the plants.

DATE OF HEADING

Rice varieties differ considerably in earliness of maturity. The early-season varieties usually mature in early August, while the late-season varieties commonly ripen in late October; consequently, hybridization between early- and late-season varieties is difficult when the plants are grown in the field. Learning how to change the

period of maturity by artificial means to enable one to cross a late-maturing variety with an early one is of utmost importance. Photoperiodism is believed to have its greatest effect on the date of maturity. The data relating to maturity are given in Table 3.

TABLE 3.—*Number of days from treatment to first heading in relation to length of day with early, medium, and late varieties of rice.*

Varieties	Treatments			
	Check	12 hours	9 hours	6 hours
1781	55	53	60	48
2407	55	47	43	42
4461	64	48	51	42
3921	75	55	49	55
9549	68	42	45	39
9554	71	42	43	42
Av.	64.7	47.8	48.5	44.7

There was considerable variation between these six varieties in the requirements of number of days from treatment to the appearance of first head. Variety 1781 required 48 days to produce the first head when treated with 6 hours of light per day, while the check plants of the same variety did not shoot until seven days later. The other five varieties reacted in a similar manner. As an average of the six varieties, the check plants required 64.7 days, while the plants exposed to 12, 9, and 6 hours of light per day required 47.8, 48.5, and 44.7 days, respectively. This shows that shortening the length of exposure hastened the period of maturity.

The number of spikes per pot was recorded each 5-day period after the time when the first head appeared in each pot. The data are given in Table 4.

Check plants of varieties 1781 and 2407 produced their first spikes about 10 days earlier than the check plants of variety 4461, and 15 to 20 days earlier than check pots of varieties 3921, 9549 and 9554. On the contrary, the plants of varieties 9554 and 9549 when treated with 6 hours of light per day produced their first head 45 days after the treatment, while varieties 4461, 2407, and 1781, similarly treated, required about 45 to 55 days from treatment to first heading. In other words, reducing the length of time that the plants were exposed to light hastened the period of maturity more in the late-maturing varieties than in the early ones.

Such results can be interpreted as it was previously, *viz.*, that the late-maturing variety usually matures in late October. The length of day in October at Hangchow is very short; consequently, shortening the length of day during the early growing season by artificial means will dispose the plants to the condition which is normally favorable for its maturity. On the other hand, the early-maturing varieties commonly ripen in the time when the length of day is very long; therefore, cutting down the length of day will not have any great effect on time of flowering. However, when the duration of light is shortened,

TABLE 4.—*The effect of length of exposure upon the number of spikes produced per pot in number of days after treatment.*

Variety	Treatment	Number of days after treatment								
		40	45	50	55	60	65	70	75	80
1781	Check pot			—	1	1	30	38	41	42
	12 hours			—	2	11	26	26	27	28
	9 hours			—	6	1	27	29	29	29
	6 hours			1	3	6	13	19	26	27
2407	Check pot		—	—	1	5	19	26	36	36
	12 hours		—	5	9	13	26	27	28	28
	9 hours		2	6	13	15	24	28	31	31
	6 hours		4	12	13	17	24	29	36	37
4461	Check pot		—	—	—	—	5	16	19	20
	12 hours		—	1	9	13	20	20	21	21
	9 hours				4	7	14	14	15	15
	6 hours		1	4	11	14	17	20	26	30
3921	Check pot								1	3
	12 hours		—	—	1	4	18	20	20	22
	9 hours			2	3	4	15	20	21	21
	6 hours			—	2	6	14	16	17	18
9549	Check pot							3	13	16
	12 hours	—	14	19	19	24	27	35	41	55
	9 hours	—	1	12	12	12	17	28	28	28
	6 hours	2	11	12	14	15	24	25	40	41
9554	Check pot								12	16
	12 hours	—	11	17	17	19	37	41	66	67
	9 hours	—	2	13	16	16	21	23	32	37
	6 hours	1	4	9	9	12	15	18	25	26

the growth of plants becomes weaker. This may hasten the blossoming period, because reproduction will take place as soon as the vegetative growth is nearly completed.

SUMMARY

A preliminary study was made to determine the relationship between length of exposure to light and plant growth in rice. The length of day was artificially shortened by covering the plants with a black cloth. Four lengths of exposure to light were made, *viz.*, check, 12 hours, 9 hours, and 6 hours.

Stooling ability of the plant was directly influenced by the length of exposure. A marked decrease in number of culms per pot was observed when the plants were grown under short day treatments.

Height of plant was increased when the period of exposure was decreased.

The period of maturity was hastened by shortening the length of day. The effect was much greater with late-maturing varieties than with varieties that normally matured early in the season.

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REGISTRATION OF STANDARD WHEAT VARIETIES, II[1]

J. Allen Clark[2]

FOLLOWING the publication in 1922 of the Classification of American Wheat Varieties (U. S. Dept. Agr. Bul. 1074), the American Society of Agronomy approved the classification and the Committee on Varietal Standardization suggested registration of all varieties described therein. The subcommittee for the registration of wheat varieties[3], acting on this suggestion, listed the official names of the varieties, in classified order, and assigned registration numbers to 229 of them. These were registered as standard varieties.

A revision of the above-mentioned classification was published in 1935 as U. S. Dept. Agr. Tech. Bul. 459 entitled "Classification of Wheat Varieties Grown in the United States". In this revised bulletin, 77 new varieties have been described. Forty-two of these have been registered by the Society as improved varieties during the past 13 years, and certificates of registration have been issued to the breeders. The remaining 35 varieties have been approved by the Committee of Varietal Standardization and Registration for registration as standard varieties.

The official names and registration numbers for these 35 varieties are given below:

Varietal Name	Reg. No.	Varietal Name	Reg. No.
Wilhelmina	279	Early Blackhull	297
Escondido	280	Superhard	298
Oregon Zimmerman	281	Cooperatorka	299
Currawa	282	Eagle Chief	300
Redhart	283	Nebraska No. 6	301
Renfrew	284	Utah Kanred	302
Arco	285	Enid	303
Golden	286	Redhull	304
Powerclub	287	Sea Island	305
Hard Federation 31	288	Whiteman	306
Axminster	289	Berkeley Rock	307
V. P. I. 112	290	Hyper	308
Montana King	291	Kruse	309
Pusa 4	292	Poso	310
Missouri Valley	293	Genro	311
Red Indian	294	Hood	312
V. P. I. 131	295	Barnatka	313
Marvel	296		

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication Dec. 9, 1935.

[2]Senior Agronomist, Wheat Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1935 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]Clark, J. Allen, Love, H. H., and Gaines, E. F. Registration of standard wheat varieties. Jour. Amer. Soc. Agron., 18:922–935. 1926.

The above-named wheats are here registered as standard varieties. They are commercially grown and have been described and officially recognized. However, no certificate of registration will be issued, such as are issued for improved varieties registered on the basis of performance in comparison with these and other standard varieties.

REGISTRATION OF IMPROVED WHEAT VARIETIES, IX[1]

J. ALLEN CLARK[2]

EIGHT previous reports present the registration of 48 improved varieties of wheat. In 1934, five varieties were registered, and the previous registration was referred to as in former years.[3]

Improved varieties approved for registration in 1935 are as follows:

Varietal Name	Reg. No.
Hymar	314
Comet	315
Clarkan	316

HYMAR, REG. NO. 314

Hymar (Wash. 2876, C. I. No. 11605) was developed in cooperative experiments of the Washington Agricultural Experiment Station at Pullman, Wash., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. It is the result of a cross between Hybrid 128 and Martin made by E. F. Gaines in 1923. It is a winter-habit, soft white-kerneled club wheat, very similar to Albit in appearance. It is a high-yielding variety and, according to Gaines, is expected to replace Albit in the Palouse section of Washington. About 1,000 bushels of seed were distributed for commercial growing in the fall of 1935. The advantages of Hymar over Albit are that it shatters less and has a heavier test weight per bushel and a higher average yield. It is similar to Albit in smut resistance. The comparative yield data upon which registration is based are shown in Table 1.

COMET, REG. NO. 315

Comet (N. No. 649, C. I. No. 11465) was developed in cooperative experiments of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Montana Agricultural Experiment Station from a cross between Marquis and Hard Federation made in 1921. The cross and selection numbers of Comet were 21202B–1–24–50–5. Large numbers of F_2 plants were grown at Bozeman and Moccasin, Mont., in 1923 and extensive F_3 populations at Bozeman, Moccasin, and Havre in 1924. The results of the F_2 and F_3 studies were published[4]. The B–1–24 F_2 plant was the highest in crude protein content of 567 in that generation grown at Bozeman.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 9, 1935.

[2]Senior Agronomist, Wheat Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture. Member of the 1935 Committee on Varietal Standardization and Registration of the Society charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, VIII. Jour. Amer. Soc. Agron., 27: 71–75. 1935

[4]CLARK, J. ALLEN, and HOOKER, JOHN R. Segregation and correlated inheritance in Marquis and Hard Federation crosses, with factors for yield and quality of spring wheat in Montana. U. S. Dept. Agr. Bul. 1403. 1926

TABLE 1.—*Comparative yields of Hymar and Albit winter wheats grown in nursery and plat experiments at Pullman, Walla Walla, and Pomeroy, Wash., 1931–35.*

Station and variety	Yield in bushels per acre						Percentage of Albit
	1931	1932	1933	1934	1935	Average	
			Nursery Experiments				
Pullman							
Hymar (new)	24.9	46.8	44.5	52.7	76.5	49.1	102.3
Albit	23.0	43.1	39.3	53.8	81.0	48.0	100.0
Walla Walla							
Hymar	54.5	37.0	43.7	29.5	45.5	42.0	107.1
Albit	45.5	36.0	49.2	20.8	44.3	39.2	100.0
Pomeroy							
Hymar	—	29.5	0.0*	37.0	54.0	30.1	103.8
Albit	—	30.8	0.0*	32.0	53.2	29.0	100.0
			Plat Experiments				
Pullman							
Hymar	—	—	46.9	47.9	47.7	47.5	109.4
Albit	—	—	45.9	40.5	43.9	43.4	100.0

*Winter killed.

From the extensive protein studies continued on many selections up to the F_6 generation it was evident that no high-yielding strains from this cross had as high a protein content as Marquis. The selection resulting in Comet first entered the nursery yield experiments at Moccasin in 1926 and the plat experiments at Havre in 1929. M. A. Bell, of the Northern Montana Branch Station, applied for registration. He and the writer were the principal breeders and jointly named[5] the variety.

Comet is a hard red spring variety with strongly awnleted spikes, white glabrous glumes, and light-red kernels. Its superior characters are drought resistance, early maturity, and high yield. Comet is being used with excellent results as a parent in further hybrid combinations. It has not been distributed for commercial growing. The yield data upon which registration is based are given in Table 2.

CLARKAN, REG. NO. 316

Clarkan (Kans. No. 505, C. I. No. 8858) was developed by Earle G. Clark, Sedgwick, Kans., from a natural Blackhull—soft wheat cross in 1916. The soft red winter wheat parent was probably Harvest Queen. The Clarkan variety was developed from a single kernel planted in 1920 and was first known as Clark's No. 40. The variety was tested by the Kansas Agricultural Experiment Station and was first distributed by Mr. Clark in 1934 after it was recommended by

[5]CLARK, J. A., and BELL, M. A. Comet wheat. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumbered Pub.] [1934] 2 pp. [Mimeographed.]

TABLE 2.—*Comparative yields of Comet and four commercial spring wheats grown in plat experiments at Havre, Moccasin, and Bozeman, Mont., 1930–35.*

Variety	Yield in bushels per acre							Percentage of Marquis
	1930	1931	1932	1933	1934	1935	Average	
Havre								
Comet (new)....	11.1	7.5	38.6	20.6	—*	13.6	18.3	118.8
Supreme.......	9.7	7.0	37.0	18.6	—*	12.2	16.9	109.7
Ceres..........	9.2	6.4	33.1	18.8	—*	10.8	15.7	101.9
Marquis.......	8.9	8.1	30.0	19.4	—*	10.6	15.4	100.0
Reward........	9.5	5.0	32.8	12.9	—*	11.4	14.3	92.9
Moccasin								
Comet.........	13.6	12.2	28.6	16.3	18.2	15.5	17.4	125.2
Supreme.......	12.3	10.0	23.6	14.1	16.9	14.6	15.3	110.1
Ceres..........	12.0	9.8	24.2	14.1	14.7	14.2	14.8	106.5
Reward........	11.8	11.0	23.5	13.6	13.9	11.9	14.3	102.9
Marquis.......	13.6	9.7	22.3	12.3	13.2	12.0	13.9	100.0
Bozeman								
Comet.........	72.2	69.1	—*	71.6	61.3	77.8	70.4	112.5
Supreme.......	71.5	67.7	—*	68.3	63.9	80.0	70.3	112.3
Ceres..........	59.6	62.4	—*	69.2	58.5	70.9	64.1	102.4
Marquis.......	69.3	58.7	—*	60.3	54.0	70.9	62.6	100.0
Reward........	54.2	48.7	—*	48.1	56.9	62.8	54.1	86.4

*Varieties badly damaged by hail, therefore data not used.

the Kansas Station and crop improvement association to replace Harvest Queen. The advantages of Clarkan over Harvest Queen are stiffer straw and higher yield. The yield data upon which registration is based are given in Table 3. Dr. J. H. Parker of the Kansas Agricultural Experiment Station applied for the registration of Clarkan, a variety developed by a private breeder.

TABLE 3.—*Comparative yields of Clarkan and other soft red winter wheats grown in nursery and plat experiments at Manhattan, Kans., 1929–35.*

Station and variety	Yield in bushels per acre								Percentage of Harvest Queen
	1929	1930	1931	1932	1933	1934	1935	Average	
Nursery Experiments									
Manhattan									
Clarkan........	31.4	46.6	50.8	71.9	23.3	30.9	31.7	40.9	125.5
Fulcaster.......	26.6	45.0	38.7	60.3	18.3	26.3	30.4	35.1	107.7
Harvest Queen..	21.9	36.5	42.0	56.0	18.9	26.0	27.1	32.6	100.0
Plat Experiments									
Clarkan.......	—	—	51.7	49.9	45.8	33.9	25.9	41.5	122.4
Fulcaster.......	—	—	50.0	48.1	44.5	31.6	26.5	40.1	118.3
Harvest Queen..	—	—	43.6	40.4	37.1	25.9	22.7	33.9	100.0

COTTON VARIETIES RECOGNIZED AS STANDARD COMMERCIAL VARIETIES[1]

H. B. Brown[2]

BELOW are brief descriptions of cotton varieties recognized by the American Society of Agronomy and the Agronomists of the Association of Southern Agricultural Workers as standard commercial varieties.

ACALA-5

Acala-5 belongs to the intermediate[3] group of cotton varieties. It was developed by C. N. Nunn of Porter, Okla., who made plant selections in a field of Acala cotton at Okema, Okla., in 1914. The variety was developed from native stock introduced from southern Mexico in 1906 by Collins and Doyle of the U. S. Dept. of Agriculture, and grown at Waco, Texas, until 1914.

Acala-5 was grown by the originator until his death in 1934. It showed a wide range of adaptability throughout the western part of the Cotton Belt, producing well on both bottom lands and upland soils.

The plants attain a height of 2 to 5 feet, depending on the supply of moisture and soil fertility; have a strong central axis and rather slender fruit branches with rather short internodes; leaves medium sized, slightly cupped; bolls 65 to 75 per

[1]These varieties were selected by a vote of 20 cotton breeders and cotton agronomists scattered throughout the cotton-growing states. The Committee was named by the Association of Southern Agricultural Workers and worked in cooperation with the Varietal Standardization Committee of the American Society of Agronomy. The Cotton Belt was divided into five districts: Western, Texas-Oklahoma, Mississippi Valley, Mississippi-Tennessee-Alabama Hill Land District, and the Georgia-Carolina District. A local committee was designated for each district, the members of which were asked to name all the varieties of the district which they considered eligible to be listed as a standard variety. Varieties thus nominated were voted on by each local committee. Varieties receiving a majority vote by the local committee were passed on to a general committee, consisting of one member from each of the districts mentioned above, and again voted on. As a result of this procedure the varieties listed were chosen. No variety was recognized unless it represented a fairly distinct type, was of considerable commercial importance in at least some part of the Cotton Belt, was grown rather extensively in 1930, and is still being grown. New strains introduced since 1930 were not listed because they are eligible for registration as New Varieties of Merit if they can qualify. Many varieties were not recognized because they were considered as being identical or very nearly the same as other varieties. The members of the different district committees were as follows: Western District, C. B. Doyle; Texas-Oklahoma, D. T. Killough, L. L. Ligon, J. S. Mogford, R. V. Miller, H. C. McNamara, J. O. Ware; Mississippi Valley, Newman Hancock, Ide P. Trotter, J. O. Ware, H. A. York, H. B. Brown; Mississippi-Tennessee-Alabama, Newman Hancock, J. F. O'Kelly, H. B. Tisdale; Georgia-Carolina, R. P. Bledsoe, R. R. Childs, E. E. Hall, P. H. Kime, C. A. McLendon. Received for publication December 5, 1935.

[2]Louisiana Agricultural Experiment Station, Baton Rouge, La. Chairman of sub-committee on cotton registration of the Committee on Varietal Standardization of the American Society of Agronomy.

[3]Intermediate group of cotton varieties according to Brown's classification of varieties. Cotton, p. 44. McGraw-Hill Book Company, New York. 1927.

pound of seed cotton; staple 1 to 1/16 inches; lint per cent 33 to 37; seed medium sized, about 4,000 to a pound, with light gray fuzz of moderate density; plants not disease resistant, only medium early, and medium prolific.

ACALA-8

Acala-8 also belongs to the intermediate group of cotton varieties. It was originated by H. G. McKeever of the U. S. Dept. of Agriculture from a plant selection made in a field of Acala cotton in 1914 at Okema, Okla. The strain was later grown in Texas and in California. The parent stock from which this variety was developed orginally came from southern Mexico and had the same history as that from which Acala-5 was developed.

Acala-8 was grown by the breeder for 15 years. It showed considerable merit in that it seemed to be adapted to a rather wide range of soil and climatic conditions in the Southwest, had large storm-proof bolls, and possessed a fiber of excellent character.

Acala-8 plants attain a height of 3 to 5 feet under fair conditions; vegetative branches are few; fruiting branches medium short-jointed, causing plants to appear semi-clustered toward the top; leaves medium large, dark green; 60 to 70 bolls per pound; staple length 1 1/16 to 1 3/16 inches; per cent lint 35 to 38; seeds light gray color, medium size, about 3,500 to a pound; plants not disease resistant; earlier than most big-boll cottons, and productive in regions where adapted.

NEW BOYKIN

New Boykin belongs to the big-boll, medium-staple group of cotton varieties. This variety originated from a plant selection made in a field of Mebane by A. M. Ferguson at Sherman, Texas, in 1913. It was introduced in 1918 and has been grown continuously since by the originator. New selections have been made within the strain and roguing practiced. New Boykin is rather early and prolific for a big-boll cotton, and yields better than the average under unfavorable growing conditions.

Plants are medium sized to large, and somewhat rangy and open; vegetative branches 2 to 5, fruiting branches 8 to 15; leaves medium in size; 75 to 80 bolls per pound; staple 7/8 to 31/32 inch; lint per cent 37 to 40; seeds gray to white, medium sized; disease resistance fair to good; medium early for a big-boll cotton and rather productive, comparatively, in regions where grown.

CLEVELAND-5

Cleveland-5 belongs to the intermediate group of cotton varieties. It was developed by the cotton breeders of the Coker Pedigreed Seed Company from a plant selection made in a field of Coker Cleveland cotton at Hartsville, S. C., in 1921. It is probable that this original plant was a hybrid between Cleveland and some long-staple variety since it had a longer staple than is usual for the Clevelands and also had some other characteristics of another variety.

Cleveland-5 has been grown by the breeder for 13 years, roguing and further selecting being done during this time to hold up the vari-

ety. This variety has as its special merits rather wide adaptability, a fair sized boll, and staple of good character.

Cleveland-5 has a medium sized plant, with 2 to 4 vegetative branches and medium length fruiting branches. Foliage is medium heavy; bolls 65 to 70 per pound; staple length 1 to 1 1/16 inches; lint per cent 36 to 40; seed brownish gray to light green, medium sized, about 3,600 to a pound; disease resistance, earliness, and productiveness medium.

CLEVELAND-884

Cleveland-884 belongs to the intermediate group of cotton varieties. It was developed by the cotton breeders of the Coker Pedigreed Seed Company from a single plant selection made in a field of Coker Cleveland 2a-2-45 at Hartsville, S. C., in 1923. The breeders have grown this variety for 14 years and subjected it to roguing and further selection. It is rather open and has a small leaf for a Cleveland. It is rather early and productive and has a fiber of good character.

This variety when grown under average conditions has plants that attain a height of 2½ to 3 feet. There are 1 to 4 vegetative branches and rather long fruit branches. Leaves are rather small; bolls 65 to 70 per pound; staple length 1 to 1 1/16 inches; lint per cent 36 to 38; seed small, 3,900 to 4,200 per pound, gray to light brown. Plants are rather early and productive and resistant to diseases in general, but have but slight resistance against wilt (*Fusarium vasinfectum*).

PIEDMONT CLEVELAND

Piedmont Cleveland belongs to the round-boll, short-staple group. It was originated by J. O. M. Smith from a plant selection made in a field of Cleveland Big Boll cotton at Commerce, Georgia, in 1914. This variety has been grown by the originator for 20 years and subjected to further selection and roguing. It has been earlier and more prolific than most other short-staple Clevelands but has a lower lint percentage.

Plants are medium to large, rather compact; foliage is medium to heavy; bolls 65 to 70 per pound; staple length 7/8 to 15/16 inch; lint per cent 34 to 36; seed brownish gray, medium sized; disease resistance, fair; earliness, medium; productiveness, good.

WANNAMAKER CLEVELAND

Wannamaker Cleveland belongs to the round-boll, short-staple group. It originated from an individual plant selection made in a field of Cleveland Big Boll at St. Matthews, S. C., by W. W. Wannamaker, St. Matthews, S. C., in 1908. The originator has grown the variety for 27 years and continued to do breeding work on it by further plant selection, mass selection, and roguing. This variety has a higher lint percentage than most Cleveland varieties, better picking bolls, and more disease resistance.

The plants are medium sized, with rather short fruit branches and 3 to 5 vegetative branches; leaves are medium large; bolls medium sized, 65 to 70 per pound; staple 7/8 to 15/16 inch; lint per cent 37 to 39; seeds brownish gray, medium sized; not a regular wilt-resistant variety but has considerable resistance; earliness medium; and productiveness good.

COOK-307-6

Cook-307-6 belongs to the round-boll, short-staple group. It originated from a plant selection made by B. C. Rhyne in a field of non-wilt-resistant Cook cotton near Auburn, Ala., in 1912. The breeding and care of the variety was supervised by the Alabama Experiment Station until 1922. It was then turned over to local breeders. The variety yields well, is very hardy, easy to pick, and very wilt resistant.

Plants are medium in size, with 1 to 2 basal vegetative branches, and rather large fruit limbs; foliage is medium to light; bolls medium sized, 70 to 85 per pound; staple 7/8 to 1 inch; lint per cent 35 to 38; seed medium sized, white to light green; disease resistance excellent; earliness medium; and productiveness good.

DELFOS

Delfos belongs to the small-boll, long-staple group. It originated from a plant selection made by H. B. Brown of the Mississippi Experiment Station in a field of Foster-120 cotton grown near Stoneville, Miss., in 1916. The variety was remarkably uniform for several years. Further plant selections have been made to preserve the type. The breeder has grown the variety for 19 years. It has been outstanding in earliness and prolificness and had a fairly uniform staple.

Delfos has rather small plants, under average conditions attaining a height of 2 to 3 feet, with 2 or 3 slender vegetative branches and numerous long slender fruit branches; leaves are small; bolls small, 75 to 85 per pound; staple length 1 1/8 to 1 3/16 inches; lint per cent, 31 to 34; seed medium sized, gray; very susceptible to cotton wilt; very early and very prolific in regions where adapted. It is especially suited to rich alluvial lands that are well supplied with moisture. (Missdel-2, Missdel-4, and other Missdel strains of the Delfos-6102 type are considered as belonging to the Delfos variety.)

DELTA AND PINE LAND-8

Delta and Pine Land-8 belongs to the intermediate group of varieties. It originated from a plant selection made by E. C. Ewing in a field of Delta and Pine Land-4 near Scott, Miss., in 1921 (Delta and Pine Land-4 was produced by crossing Mebane and Polk, the latter a local variety). Delta and Pine Land-8 was grown and tested by the breeder for about 10 years. More recently it has been grown and selected by the Louisiana Experiment Station as a good variety for northern Louisiana. It is especially adapted to poor hill lands because the plants are vigorous in growth, have a high lint percentage, and a fair staple length.

The plants are medium large, attaining a height of 3 to 6 feet, compact with rather short fruit branches; foliage is medium heavy; bolls medium sized, 70 to 80 per pound; staple length 1 to 1 1/16 inches; lint per cent 36 to 38; seed medium sized, gray; disease resistance fair to good; earliness fair; and productiveness fair.

DELTA AND PINE LAND-10

Delta and Pine Land-10 belongs to the intermediate group of varieties. It was produced by E. C. Ewing of Scott, Miss., by crossing

Express-122 and a non-commercial hybrid containing Express and Mebane blood. The cross was made in 1920. Individual plants were selected in the F_2 planting and subsequently in progeny rows. The variety was grown and tested by the breeder for a period of 11 years. It has proved to be productive over a large area of the Central South, and has a satisfactory staple length for a short cotton.

Delta and Pine Land-10 has medium sized plants, being more spreading than Delta and Pine Land-8, but not as tall; leaves are medium to fairly large, distinctly light green; boll size medium, 70 to 80 to a pound; staple length 1 to 1 1/16 inches; lint per cent 33 to 36; seed medium sized, brownish gray; disease resistance fair; medium early, and a good producer.

DELTATYPE WEBBER

Deltatype Webber belongs to the big-boll, long-staple group of varieties. It was developed from a plant selected in a field of Webber-82 near Hartsville, S. C., in 1915 by the cotton breeders of the Coker Pedigreed Seed Company. The variety has been subjected to further selection and roguing for a period of 19 years.

Plants are vigorous, have large bolls for a long-staple cotton, and staple of excellent character. The plants are erect, rather stocky, vigorous, 3 to 4 feet tall; 1 to 3 sharply ascending vegetative branches and numerous short fruiting branches; foliage medium heavy; bolls medium large, 60 to 65 per pound; staple length 1 3/16 to 1 3/8 inches; lint per cent 31 to 33; seed medium sized, 3,750 per pound, light gray to brown; susceptible to wilt; medium late, but productiveness good for a variety of its staple length.

DIXIE-TRIUMPH

Dixie-Triumph belongs to the medium-late, small-boll, short-staple group of varieties. A cross between Mebane Triumph and Dixie wilt-resistant cotton was made by W. W. Gilbert and Joe M. Johnson on the farm of Mr. Johnson near Monetta, S. C., in 1908. Hybrid strains of the cross were later grown on several wilt-infected soils in South Carolina, Georgia, and Alabama, and from one of these plantings Dixie-Triumph was developed. The variety was introduced commercially about 1915. L. O. Watson, an assistant to Mr. Gilbert, continued the breeding work after Mr. Gilbert was assigned other duties.

Dixie-Triumph resembles the Dixie parent in general plant form. It is a good, healthy, vigorous-growing variety and is very resistant to cotton wilt (*Fusarium vasinfectum*) under most conditions.

Plants large and spreading, attaining a height of 3 to 6 feet; branches are long; leaves medium sized; bolls medium sized, 65 to 75 per pound; staple 7/8 to 1 inch; lint per cent 33 to 35; seed medium small, tawny gray; disease resistance good; medium late but earlier than Dixie. Productive if boll weevils are controlled.

DIXIE-14

Dixie-14 belongs to the medium-late, small-boll, short-staple group of cotton varieties. It was developed from a plant selection made by S. P. Coker, Hartsville, S. C., in a field of U. S. D. A. Dixie cotton.

The original selection was made in 1920. The variety has been grown by the originator for 14 years and subjected to roguing and further selection. The special merits of the variety are its excellent wilt resistance and good production.

Under average growing conditions Dixie-14 plants attain a height of 3 feet, and are somewhat stocky; basal branches are small, fruiting branches long, producing a spreading type of plant; leaves are medium to heavy; bolls medium sized, 65 to 70 per pound; staple 31/32 to 1 1/32 inches; lint per cent 34 to 38; seed medium sized, greenish gray; disease resistance good; earliness medium; productiveness good.

EXPRESS-121

Express-121 belongs to the small-boll, long-staple group of varieties. It originated from a single plant selection made by W. E. Ayres in a field of Express-432 near Stoneville, Miss., in 1921. (The Express-432 was a selection from the original strain of Express.) Express-121 has been grown by the originator since 1921 and has been subjected to testing and further selection. Special merits of the variety are its earliness and fair degree of wilt resistance.

Plants are medium tall, open, and spreading with rather long fruit branches. The foliage is light; boll size small, 75 to 80 per pound; staple length 1 1/8 to 1 3/16 inches; lint per cent about 32.5; seed medium small, gray; disease resistance good; earliness and productiveness good.

LIGHTNING EXPRESS

Lightning Express belongs to the small-boll, long-staple group. It originated from a single plant selection made by the cotton breeders of the Coker Seed Company in a field of Express-350 grown near Hartsville, S. C., in 1922. The variety was grown by the originator for about 15 years and further plant selections made. The special merits of the variety are earliness, prolificness, and good length staple.

Plants are of medium size with few vegetative branches, and medium length fruit branches; foliage is rather light; bolls small, 75 to 85; staple length 1 1/8 to 1 3/16 inches; lint per cent 32 to 34; seed small, gray; disease resistance good; very early and prolific.

HALF AND HALF

Half and Half belongs to the round-boll, short-staple group of varieties. It was developed by selection from Cook by H. H. Summerour of Duluth, Georgia. The first selection was made in 1906. Selection work has been continued from that date to the present. The chief merits of the variety are its earliness, prolificness, high lint percentage, and adaptation to poor land.

Plants of Half and Half are small to medium in size, medium compact, with medium sized leaves; bolls medium sized, 65 to 70 per pound; staple 3/4 to 7/8 inch; lint per cent 40 to 45; seed small, grayish brown; early and productive but very susceptible to wilt and anthracnose diseases.

KASCH

Kasch belongs to the big-boll, medium-staple group of varieties. It was selected from Mebane Triumph at Lockhart, Texas, about 1912 by Ed Kasch of San Marcos, Texas. Individual boll and plant selections are made each year. The special merits of the variety are to be found in its large bolls, relatively high percentage of lint, good character of staple, and good production under Texas conditions.

Plants medium to large, rather stocky; normally have 2 to 4 vegetative branches and 8 to 15 fruiting branches; leaves are medium to large; bolls large, 45 to 60 per pound; staple 15/16 to 1 inch; lint per cent 38 to 41; seed medium sized, gray to white; disease resistance medium; earliness medium; productiveness medium.

LONE STAR

Long Star belongs to the big-boll, medium-staple group of varieties. It originated from a single plant selection made by D. A. Saunders in a field of Jackson cotton near Waco, Texas, in 1904. The variety has been selected for 30 years, the first 14 years by D. A. Saunders; more recently by John Gorham and Son of Waco, Texas. The special merits of the variety consist in its large, storm-proof bolls, uniform staple, and drought resistance.

The plant size is medium to large, and there are commonly 2 to 4 vegetative branches; leaves are large; bolls large, 45 to 60 per pound; staple 31/32 to 1 1/32 inches; lint per cent 38 to 41; seed medium to large, light gray to white; disease resistance fair; earliness medium; productiveness good.

MEBANE

Mebane belongs to the big-boll, medium-staple group of cotton varieties. It was developed by A. D. Mebane of Lockhart, Texas, by plant selection. The selection work was started in 1882, according to W. P. Patton, Jr., of Lockhart, Texas, the present breeder, with Boykin Storm-proof as parent material. After a few years of selection, the characters of the variety became fairly well fixed. Breeding by making individual plant selections and massing strains of similar characters has been practiced. The work is still being continued.

The special merits of Mebane cotton are to be found in its large storm-proof bolls, high lint percentage, and excellent staple.

Plants of the variety are medium sized, sturdy in growth, with 2 to 4 vegetative branches; leaves are medium large to large; bolls 50 to 65 per pound; staple length 15/16 to 1 1/16 inches; lint per cent 37 to 40; seed medium sized, gray to white; disease resistance fair; earliness medium; productiveness good under Texas conditions, but rather poor, comparatively, in more humid regions.

MISSDEL

Missdel belongs to the big-boll, long-staple group of cotton varieties. It originated from a plant selection made by H. B. Brown of the Mississippi Experiment Station in a field of Foster-120 cotton grown near Stoneville, Miss., in 1916. This variety was selected in the same field as Delfos and was known as Delfos-631 for several years but was named Missdel in 1926 since it represented a distinct varietal type.

It differs from Delfos in that the main stem is more prominent, fruit branches shorter, bolls larger, and staple longer. The strain when first selected was lacking in uniformity, but it has been improved and made more uniform through further individual plant selection by the cotton breeders of the Mississippi Delta Experiment Station. Missdel has been characterized by its good production, excellent staple, good boll size, and the storm resistance of its bolls.

Plants are medium sized, attaining a height of 3 to 5 feet, with a rather prominent main stem, and numerous medium length fruit branches; leaves medium sized; bolls medium large, 68 to 78 per pound; staple length 1 5/32 to 1 3/16 inches; seed medium large, white to gray; plants susceptible to wilt but somewhat more resistant than Delfos; early and productive.

STATION MILLER

Station Miller belongs to the big-boll, medium-staple group. It originated from a single plant selection made by J. F. O'Kelly in 1926 in a field of Miller[4] cotton grown near State College, Miss. Breeding work is being continued by the originator by the use of field-selected seed, or by the use of seed from high yielding progenies. The main merits of this variety consist in its prolificness for a variety with a good sized boll and its wilt resistance. It is earlier than the parent variety, more prolific, and has a higher lint percentage.

The plants are medium sized, with 1 to 3 vegetative branches; foliage is medium to heavy; bolls medium sized, 60 to 65 per pound; staple length about 1 inch; lint per cent 32 to 36; seed medium to large, white to gray; disease resistance good, especially wilt resistance; earliness medium; fruits slowly but produces well under favorable conditions.

MEXICAN BIG BOLL

Mexican Big Boll belongs to the big-boll, medium-staple group of varieties. It was developed from an individual plant selection made by the cotton breeders of the North Carolina Experiment Station in a field of Hope's Mexican Big Boll cotton grown near Rocky Mount, N. C., in 1917. The variety has been re-selected 8 or 10 times since that time, increase plats grown in isolation and rogued. The variety shows merit in that it has large bolls, good yields of uniform staple of good spinning quality, and disease resistance.

The plants of Mexican Big Boll are medium large, rather open, and have fairly heavy foliage. Bolls are large, 60 to 65 per pound; staple 1 to 1 1/16 inches in length; lint per cent 34 to 37; seeds medium to large, gray; disease resistance fair; earliness medium; and productiveness good.

OKLAHOMA TRIUMPH-44

Oklahoma Triumph-44 belongs to the early, small-boll, short-staple group of varieties. It originated from a plant selected in a field of Mebane cotton near Stillwater, Okla., in 1914. L. L. Lignon, cotton breeder for the Oklahoma Experiment Station, made the orig-

[4]Miller was very similar to Rowden, if not identical.

inal selection and has continued plant selection in the variety each year since 1914. The variety is outstanding in its earliness, prolificness, and good character of staple. It resembles the parent variety but little.

Plants are rather open in growth, medium sized, with 2 to 4 vegetative branches; foliage is relatively light; balls small, 70 to 90 per pound; staple length 29/32 to 1 inch; lint per cent 34 to 36; seed medium sized, gray to white; disease resistance fair; earliness excellent; productiveness good.

PIMA

Pima is an Egyptian variety that was developed in Arizona. Afifi cotton was imported from Egypt by the cotton breeders at the U. S. Field Station at Sacaton, Ariz., and selections made. The first outstanding strain obtained was designated as Yuma. An individual plant selection made in a field of Yuma at Sacaton in 1910 produced the variety Pima. The variety was tested for 5 years before it was introduced commercially. The special merits of Pima cotton are to be found in the length, strength, and fineness of its fiber, adapting it to purposes for which Egyptian cotton in general is used—fine dress goods, high grade tire fabrics, etc.

Pima plants, when grown under average conditions, attain a height of about 6 feet. They have few or no vegetative branches and many long fruiting branches. Leaves are large, glossy, nearly glabrous, and dark green; bolls small compared with Upland cotton, about 150 per pound; staple 1 9/16 to 1 11/16 inches; lint per cent about 25; seed small, about 13 grams per 100, very dark brown, partly fuzzy, fuzz greenish; susceptible to disease, especially "black arm". The variety is early for Egyptian type, but late compared with Upland. Average yield of lint per acre in Salt River Valley, Ariz., is about 270 pounds.

ROWDEN

Rowden belongs to the big-boll, medium-staple group of varieties. This variety was developed from Bohemian cotton by Rowden Brothers at Wills Point, Texas, about 1890. The chief merits of the variety are to be found in its large storm-proof bolls of fluffy, easily picked, mass of seed cotton, and hard-bodied, good quality fiber.

The plants are large, rangy for a big-boll variety, with rather profuse branching; leaves are very large and heavy; bolls large, 50 to 65 per pound; staple 15/16 to 1 1/32 inches; per cent lint 34 to 37; seed very large, fuzzy, and white; disease resistance fair; earliness medium; productiveness fair to good.

ARKANSAS ROWDEN-40

Arkansas Rowden-40 probably should be classed with the big-boll, medium-staple group of cotton varieties, but the boll is somewhat smaller than the average for the group. This variety originated from a single plant selection made by J. O. Ware, Fayetteville, Ark., in a field of Rowden Brothers' Rowden near Scott, Ark., in 1921. The strain was tested and increased by the Arkansas Experiment Station for several years and then turned over to R. L. Dortch for multiplication and seed sale. This variety has considerable vigor and yields better

than many varieties when grown under poor conditions. It has considerable wilt resistance and lighter foliage than most strains of Rowden.

Plants are rather large, with few basal limbs; foliage is medium; bolls medium sized, 55 to 70 per pound; staple length 1 to 1/16 inches; lint per cent 32 to 36; lint index 7.50 to 8.75; seed medium sized, 14 to 16 grams per 100, whitish gray; disease resistance medium to rather resistant; earliness medium; productiveness good.

TOOLE

Toole belongs to the medium-late, small-boll, short-staple group of varieties. This variety was developed from Peterkin by W. W. Toole, Augusta, Ga. The variety was introduced prior to 1907, but the exact date was not obtained by the writer. The special merits of the variety are to be found in its wilt resistance and vigor or production when grown under hard conditions of culture.

Toole has rather large plants with a tendency to semi-cluster; bolls medium, 65 to 75 per pound; staple short, 15/16 inch; lint per cent 35 to 37; seed small, fuzzy, light brownish-gray; disease resistance good; medium late but fairly productive if boll weevils are controlled.

STONEVILLE

Stoneville belongs to the intermediate group of cotton varieties. It originated from an individual plant selection made by H. B. Brown in a field of Lone Star 65[5] cotton grown on the farm of the Stoneville Pedigreed Seed Company near Stoneville, Miss., in 1923. The variety has been further selected, increased, and tested by the breeder for 12 years. The main features of merit of the variety are its earliness, prolificness, and uniformity of staple of fair length.

Plants of the variety are medium sized, medium spreading, with two or more vegetative branches if not spaced closely; foliage is medium light; bolls medium sized, 70 to 80 per pound; staple length 1 to 1 1/16 inches; lint per cent 33 to 36; seed medium small, gray; disease resistance poor; very early and productive.

TRICE

Trice belongs to the early, small-boll, short-staple group of varieties. The variety was developed from plant selections made by S. M. Bain of the Tennessee Experiment Station in a field of cotton known locally in Chester County, Tenn., as "Big-Boll Cluster". The first selection was made in 1906. The Tennessee Experiment Station has continued to grow Trice for about 20 years. Some further selections have been made. The variety has been outstanding in earliness and prolificness.

Plants are rather small, 2 to 5 feet tall, rather compact, many approaching the semi-cluster type; basal limbs few; leaves light green, medium sized; bolls rather small, 74 to 84 per pound; staple fine, 7/8 to 1 inch, irregular; lint per cent 31 to 33; seed medium small, 13 to 14 grams per hundred, tawny colored; disease resistance poor; very early and prolific.

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[5]Lone Star-65 was probably a natural cross between Trice and Saunders' Lone Star.

WILDS

Wilds belongs to the big-boll, long-staple group of varieties. It was produced by crossing Lightning Express, which was used as the pistillate parent, with Deltatype Webber. The cross was made in 1919 at Hartsville, S. C., by the Coker Pedigreed Seed Company. Since that date the variety has been subjected to additional selection, roguing and testing by the breeder. The special merits of the variety are to be found in its productiveness and boll size, which are excellent for a cotton of its staple length, and in its long, and excellent staple.

Plants are medium sized and somewhat stocky like the Deltatype parent; 1 to 4 vegetative branches, numerous rather short fruit branches; foliage heavy; bolls medium large, 60 to 75 per pound; staple length 1 3/16 to 1 3/8 inches; lint per cent 31 to 34; seed large, gray to light brown; not wilt resistant; earliness medium; productiveness good for an extra-staple variety.

BOOK REVIEW

WEED SEEDS

By Emil Korsmo. Oslo, Norway: Grøndahl & Sons. 175 pages, illus. 1935. $10.

THIS book is destined to aid materially in weed and seed investigations. It contains a wealth of material, which represents the culminating effort of a life time devoted to a subject that in most countries has been somewhat neglected. Some idea of the scope and general utility of the book is apparent to any one interested in weeds from the following brief description of its contents.

The book contains descriptions and illustrations of 306 plant species characterized as weeds. The species included are those found commonly in East, West, Central and North Europe, and less commonly in South Europe and North America. There are 34 full-page colored plates each with illustrations of nine species. Each illustration in clear detail is a reproduction from hand-made plates and includes all or part of the inflorescence, a fruit depicting the method of dehiscence (for dehiscent fruits), natural and enlarged views of the seed, and finally transverse and longitudinal sections of the seed showing the position and relative size or thickness of the endosperm, embryo, and seed coats. The illustrations are all in natural colors although it must be recognized that the colors exhibited by many species are not the same in every geographical area. Preceding each plate is a description in Norwegian, German, and English of each species figured. The description covers the type of inflorescence, kind of fruit (silicle, achene, capsule, etc.), shape and size of the seed, color and appearance of the seed coat, and finally the distribution, common habitat, and methods of seed dissemination. The species are arranged according to what the author calls life forms, designated by symbols, e.g., annuals, winter annuals, biennials to perennials and perennials with rootstocks. Within each group the species are arranged in families. From the standpoint of the teacher or the taxonomist, the major

grouping is somewhat unsatisfactory, but the aim of the author has been to serve the agriculturist as well as the botanist, recognizing at the same time that the life history of a given species is affected by geographical distribution. The index lists alphabetically the botanical names of all the species together with their common names in 11 languages.

The book will doubtless find a place on the reference shelves of those who teach courses dealing with weeds and seeds and will also serve as a material aid to the investigator and the seed analyst. (R. H. P.)

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A TENTATIVE RECOMMENDATION OF TECHNIC FOR GRAZING EXPERIMENTS ON RANGE PASTURES IN ARID OR SEMI-ARID REGIONS[1]

Preparation of plan.—All publications dealing with the problem in hand should be examined before the working plan of the experiment is prepared in final form.

Location of grazing units.—Range grazing experiments to determine carrying capacity or the influence of seasonal grazing should be located on land representative of large areas of grazing land in the region to be served by this experiment. The large areas required for pastures in range grazing studies will probably be much more variable than would be acceptable for farm pasture experiments, but every

[1]Prepared by Dr. George Stewart, Senior Forest Ecologist, Division of Range Research, Forest Service, U. S. Dept. of Agriculture, with the assistance of M. W. Talbot and L. C. Hurtt, for the Joint Committee on Pasture Research. See this JOURNAL, Vol. 27: 1018–1019. 1935.

care should be taken to have the various range pastures or roughly comparable productivity, that is, they should be of approximately equal heterogeneity as to soils, exposure, slope, etc. The various pastures should be approximately equal in north to south exposure.

Size of grazing units.—Each unit grazed by one group of animals should be large enough to support over the experimental period, preferably 20 animals and at least 10. All treatments should be duplicated or run in a graduated series with each of five or six pastures used to obtain a point in order to determine where a break in the line might occur; when excessive variability requires division of pastures into smaller areas, all pastures should be divided in the same manner and at the same time.

Provision of drinking water and fences.—In range pastures one very important item is a proper distribution of drinking places. If this does not occur naturally water should be hauled to such localities as will avoid greatly unequal use of the forage. All experimental pastures should be securely fenced.

Rodent injury to pastures.—The nature and degree of rodent injury should be determined. Rodent-proof enclosures are a necessary part of many range grazing experiments.

Kind of livestock.—The kind of animals used and their sex should represent one of the most important phases of the livestock industry in the region. If lambs or calves are included with their mothers, each grazing unit should have an equal proportion of young and these of approximately equal age. When lamb crops or calf crops are to be used as a measure of treatments, the number of lambs or calves will vary somewhat. Mature stock alone will yield more reliable data regarding gain in flesh, or in flesh and wool in case of sheep, but if ewes and lambs, or cows and calves are usually grazed together on the ranges, such practice deserves representation in the experiment.

Reserve pastures and rotation of animals.—A given group of animals should not be rotated unless all are rotated. Under yearlong grazing additional pastures may be required to provide alternate seasonal use in order to prevent a large variable in the experiment as a result of wasting feed during one season and being short during another.

Weighing the animals.—Individual weights should be obtained at the beginning and at the end of the experimental period, and at intervals of about 4 weeks. In order to overcome variations in the weight of animals resulting from drinking water, weighings should be made soon after all animals have had ample opportunity to drink as much as they desire. Triplicate weighings on successive days are not feasible with the nervous semi-wild cattle used in range grazing experiments.

Supplemental feeding.—Supplemental feeding during the grazing test should be resorted to only in extreme emergency such as severe drought, supplemental pasturage being more satisfactory if the total available feed must be increased. When such an addition is made it should include all animals and the period should be for not less than 48 hours, and 72 or more are preferable.

Rate of grazing.—Rate of grazing should be expressed as unit-days or unit-months per acre. It may be wise in some cases to adjust the number of animals on a pasture from time to time to keep pace with

the forage growth, for example, in connection with study of seasonal use where it is desirable to obtain an equal degree of utilization in all pastures.

Measurement of feed consumed.—The amount of feed consumed should be measured as accurately as possible. This depends on volume present and on percentage utilization, both of which are derived by estimates. A series of estimates on small plots at definite mechanical intervals in the pasture should be provided. The person conducting the experiment should satisfy himself that his data are as accurate and reliable as feasible. Small estimate plots of 100 square feet or 200 square feet or other definite small area replicated at mechanical intervals in all parts of the area constitute one desirable method. In each large pasture 50 to 100 small plots are not too many to obtain representative data.

Plant population studies.—Forage inventory surveys to determine the plant population or species composition of the flora should be made at the beginning and at the end of the experiment, and at intervals of 3 to 5 years in a long-time trial. For this purpose there should be 3 to 5 or more permanent quadrats in each pasture charted annually, and in pastures where browse contributes appreciably to the feed these quadrats should be supplemented with annually charted brush plots. (For description see Pickford and Stewart "Ecology", 1935.)

Cost studies.—Cost studies should be made only for widely different treatments and these definitely provided for in the plan of the experiment.

Duration of experiment.—Grazing experiments should be continued for 6 to 10 years or longer if necessary in order to obtain a fair average of favorable and unfavorable seasons. The experiment should be fortified with ordinary weather instruments, and additional ones when the nature of the problem requires them.

Publication of results.—In reporting the results of the experiment the researcher should present (1) review of publications dealing with the problem in hand, (2) the history of the grazing area, (3) the nature of the forages, (4) the season and kind of use, and (5) a statistical analysis of results wherever possible.

Precautions required to promote accuracy of results.—The accuracy of range grazing experiments would undoubtedly be increased by a determination of the total digestible nutrients obtained by the grazing animals, but until more digestion trials are conducted with range forages efforts should be made to reduce the controllable large variables such as those consequent upon the heterogeneity of large areas in respect to soil, slope, exposure, and vegetative cover, and to differences in the utilization of forage. Such variables are likely to be greater in range than in farm pasture experiments. More information is needed on methods of conducting range grazing experiments. It is not known whether all the data from small plots apply to the larger more heterogeneous range plots required by sparse vegetation, but the principles should be the same.

A WORD ABOUT ADVERTISING

BEGINNING with this issue of the JOURNAL, we take pleasure in acknowledging again a renewal of advertising contracts by that small group of advertisers who have supported the JOURNAL through good times and bad, and in addition, welcome one or two newcomers to our pages, as well as others who have used the JOURNAL occasionally in the past. This pronounced renewal of interest in the JOURNAL as an advertising medium would seem to justify a word at this time regarding our relations to our advertisers.

Generally speaking, advertising in a scientific journal with a rather limited circulation is looked upon by the advertiser largely as a gesture of good will, but we feel that the JOURNAL of the American Society of Agronomy covers a valuable potential market for every advertiser who uses its pages, and that advertising in the JOURNAL is not wholly an act of charity.

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YIELD AND COMPOSITION OF EARED AND EARLESS MAIZE PLANTS IN A SELFED LINE SEGREGATING BARREN STALKS[1]

R. J. GARBER, R. B. DUSTMAN, AND C. R. BURNHAM[2]

DURING the summer of 1934 a selfed strain isolated from Boone County White corn was observed to contain red-leaved plants. Closer examination showed that all the red-leaved plants were earless or barren. In the culture there was a total of 54 eared plants and 26 that were barren. This same strain was planted in 1935 and of the resultant plants 68 were eared and 25 were earless. These data indicate monohybrid segregation and suggest that the hereditary difference between the two types of plants involves only a single gene. This particular culture by 1934 had been selfed for 13 years. It is not known when the mutation occurred, but cultures grown from remnant seed of previous years showed it to have been segregating at least two generations earlier. With the exceptions to be discussed later, the eared and earless plants were very similar in general appearance, the differences becoming apparent after the ear shoots had appeared. On earless plants the normal concavity of the internodes is completely lacking or only slightly developed.[3] In two cases earless plants produced tillers and in both cases these tillers also bore small ears.

In 1934, Brunson and Latshaw[4] of Kansas reported on the effect of failure of pollination on composition and yield of corn plants. These authors included a review of the pertinent literature. In the Kansas

[1]Contribution from the Department of Agronomy and Genetics and the Department of Agricultural Chemistry, West Virginia Agricultural Experiment Station, Morgantown, W. Va. Published with the approval of the Director, West Virginia Agricultural Experiment Station, as Scientific Paper No. 158. Reeived for publication D ecember 21, 1935.

[2]Agronomist, Agricultural Chemist, and Assistant Geneticist, respectively.

[3]This earless character is similar to the "barren-stalk" characters studied by J. D. Hofmeier, with the exception that in the present case the tassels of earless plants are similar to those of normal sibs, whereas one of the "barren stalk" characters had few or no side branches in the tassel. As yet the new earless character has not been tested for genetic identity with the two barren stalk characters. See Emerson, R. A., Beadle, G. W., and Fraser, A. C. A summary of linkage studies in maize. Cornell Univ., Agr. Exp. Sta. Mem. 180. 1935.

[4]BRUNSON, A. M., and LATSHAW, W. L. Effect of failure of pollination on composition of corn plants. Jour. Agr. Res., 49:45-53. 1934.

material, failure to produce well-filled ears was due to poor pollination, whereas in the material described here the earless condition was genetic, earless plants producing neither cobs nor grain. Since the earless character appeared in an inbred strain, the genetic backgrounds of normally eared and of earless plants should be similar. Such material was considered favorable for making a study of relative yields and plant composition.

YIELD

In 1934 the culture under consideration was planted in two individual row plats on different experimental areas. The plants were spaced approximately 15 inches apart along the row, and since the earless character does not appear until late in development, the two types, of course, occurred at random. Entire plants were harvested by cutting the stalk at the surface of the ground when the plants had reached the proper stage of maturity for ensiling. Leaves, stems, and ears on some of the plants were separated in paper bags. Each individual plant was placed in a muslin bag, hung in the drying house, and later weighed to determine the amount of dry[5] material. The plants harvested for chemical analysis were weighed, cut fine, and preserved in alcohol.

Each earless plant was paired with one that was normally eared. In no case was a paired eared and earless plant separated by more than a few feet along the row and in most cases the paired plants were adjacent (15 inches apart).

The average dry weights of the plants and plant parts, together with the significance of the differences determined by Student's method, are shown in Table 1. With respect to the entire plant the eared plants averaged 43.2 grams heavier than the earless ones, a difference which is undoubtedly significant (column 6). This difference is 31.1% of the average weight of the eared plants. With respect to the weights of leaves alone (including sheaths), the stems alone, or leaves and stems combined, the differences are significant and are in favor of the earless plants. These differences expressed in percentages of the weights of the corresponding parts of eared plants are, respectively, 36.3, 39.5, and 30.5. It is obvious from these data that the leaves alone or the stems alone of the earless plants were

TABLE 1.—*Average weights of entire and of certain parts of paired eared and earless plants of selfed strain of corn grown on the Agronomy Farm, 1934.*

Plant parts	No. of paired plants	Average dry weight in grams of		Difference	Odds	Difference in per cent of eared
		Eared	Earless			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Entire plant	14	138.7	95.5	43.2	9999+	31.1
Leaves and stems	14	73.2	95.5	22.3	768	30.5
Leaves, including sheaths	8	33.9	46.2	12.3	300	36.3
Stems	8	39.0	54.4	15.4	160	39.5

[5]At the time of weighing the material contained about 1 % moisture.

heavier than the corresponding parts of the plants with ears. On the other hand, the average weight of entire plants which bore ears was greater than the average weight of entire plants which did not produce ears. Apparently only part of the material which ordinarily would be stored in the ear is stored in the other parts of earless plants.

In 1935 additional data with the same selfed line were collected. The procedure throughout was similar to that followed the previous year except that no attempt was made to determine the weights of the leaves and stems separately. The data obtained are shown in Table 2.

TABLE 2.—*Average weights of entire and of certain parts of paired eared and earless plants of a selfed strain of corn grown on the Agronomy Farm in 1935.*

Plant parts	No. of paired plants	Average dry weight in grams of		Dif-ference	Odds	Difference in per cent of eared
		Eared	Earless			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Entire plant............	17	174.3	118.1	56.2	9999+	32.2
Leaves and stems........	17	80.8	118.1	37.3	9999+	46.2

As in the previous year, the average weight of entire eared plants was significantly greater than that of earless plants, the difference being 32.2% of the former. With respect to the average weight of leaves and stems combined, the earless plants were heavier, the difference being 46.2% of the weight of the eared plants. In general, the relative yields obtained in 1935 were similar to those obtained in 1934.

In another culture, in the first generation of selfing, earless plants were found to be segregating. Weights on six pairs were determined. All differences were similar in direction to those for the other earless character. There was more variation, however, which resulted in odds which are barely significant.

COMPOSITION

At the time of harvest the most striking apparent difference between the two types of plants other than the presence or absence of ears was the coloring in the leaves. The earless plants showed an abundance of red coloring in the leaves and leaf sheaths, whereas the eared plants showed very little or none. The difference in the appearance of the leaves after extraction of most of the chlorophyll followed by treatment with iodine solution is shown in Fig. 1. The treatment removed some red pigment along with the chlorophyll. The two leaves at the left are from eared plants and the two at the right are from earless plants.

In all, eight plants were subjected to a chemical analysis similar to that ordinarily used for determining certain constituents of feed.[6]

[6]Methods of Analysis of Association of Official Agricultural Chemists. Ed. 2. 1925.

Two plants or the specified parts of two plants were used to make up a sample for each analysis reported in Table 3.

The data in columns 2 and 3 show that the eared plants contained somewhat more free water and were heavier than the earless plants. On the other hand, the leaves alone of the earless plants were about

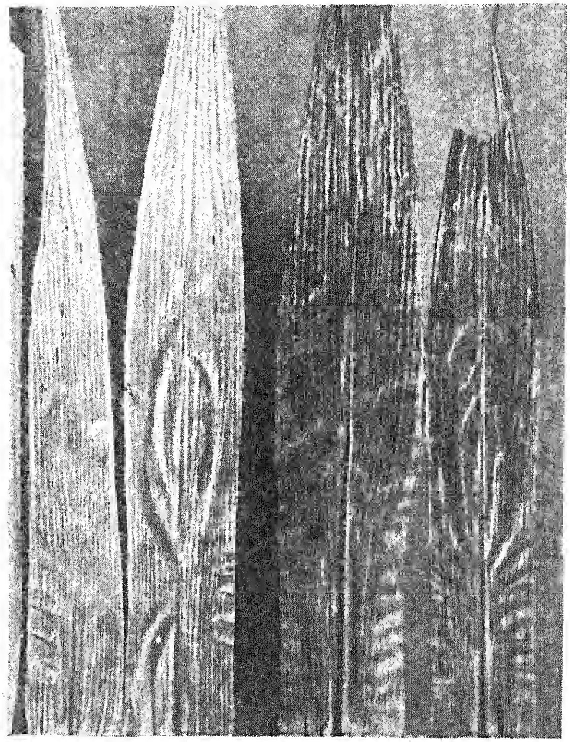

FIG. 1.—Corn leaves treated with iodine solution after extraction of the chlorophyll from eared (left) and earless (right) plants occurring in the same selfed strain grown on the Agronomy Farm in 1934. The dark streaks indicate the presence of starch, while the dark solid color indicates the presence of pigmentation.

20% heavier than the leaves of the eared plants. Apparently the earless plants were slightly the more mature at the time of harvest. The relative weights of the two types of plants have been discussed above in connection with more adequate data and need not be repeated here, other than to point out again that the total weight of the eared plants is considerably greater than the total weight of the earless plants.

Comparing the percentage compositions (columns 4, 5, 6, 7, and 8, Table 3) of entire plants, it is found that the earless plants analyzed higher in ash, crude protein, and crude fiber and lower in ether extract and nitrogen-free extract. With respect to the leaves alone,

TABLE 3.—*Weights and various constituents of eared and earless plants of a selfed strain of corn grown on the Agronomy Farm in 1934.*

Sample*	Percentage H_2O at harvest	Dry matter, grams	Percentage composition on dry matter basis				
			Ash	Crude protein	Ether extract	Crude fiber	N-free extract
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
I, entire plant, *earless*.	66.50	183.1	5.08	12.76	2.39	18.74	61.00
II, entire plant, *eared*.	67.16	230.7	4.15	9.95	3.51	17.05	65.32
III, leaves, *earless*†. . . .	69.28	78.8	6.23	13.04	3.67	18.71	58.35
IV, leaves, *eared*.	70.91	65.3	6.68	13.17	4.84	22.81	52.47
V, stems, *earless*.	67.79	91.0	3.04	10.80	1.13	18.28	66.73
VI, stems and ears, *eared*.	69.93	205.2	2.55	7.89	2.05	18.25	69.23

*Each sample from two plants.
†Samples III and V from same plants; likewise samples IV and VI from same plants.

the earless plants were slightly lower in percentage of ash and of crude protein, distinctly so in ether extract and crude fiber, and markedly higher in percentage of nitrogen-free extract. The stems and ears together from the eared plants ran lower in ash and crude protein but higher in ether extract and nitrogen-free extract than did the stems of the earless plants. Practically no difference was found in the percentage of crude fiber. These analyses show that certain differences in percentage compositions of ash, crude protein, ether extract, crude fiber, and nitrogen-free extract existed between eared and earless plants at the time of harvest.

Certain carbohydrate fractions of the two types of plants were determined by the official methods, using samples of the same material previously reported. The percentages of the several constituents are shown in Table 4, columns 2, 3, 4, 5, and 6. The analyses of

TABLE 4.—*Carbohydrate constituents of eared and earless plants of a selfed strain of corn grown on the Agronomy Farm in 1934.*

Sample*	Percentage composition on dry matter basis				
	Total sugar (as invert sugar)	Reducing sugar (as glucose)	Starch (0.9 x glucose value)	Hemicellulose (as glucose) (1% HCl)	Total carbohydrate
(1)	(2)	(3)	(4)	(5)	(6)
I, entire plant, *earless*.	26.64	7.93	3.36	11.41	41.41
II, entire plant, *eared*. .	17.91	4.19	14.21	13.81	45.93
III, leaves, *earless*†.	18.12	5.61	1.93	12.71	32.76
IV, leaves, *eared*.	13.39	4.99	2.66	11.61	27.66
V, stems, *earless*.	35.36	32.84	3.88	7.52	46.76
VI, stems and ears, *eared*.	25.08	17.78	12.02	10.29	47.39

*Each sample from two plants.
†Samples III and V from same plants; likewise samples IV and VI from same plants.

entire plants showed that the earless individuals contained distinctly more total sugar and reducing sugar and distinctly less starch than was contained in the eared individuals. With respect to the hemicellulose fraction and total carbohydrates, there was relatively less difference, but the difference that was found was in favor of the eared plants. The analyses of the leaves alone for total sugar, reducing sugar, and starch showed differences similar to but somewhat less marked than those for the entire plants. The leaves from earless plants showed a considerably higher percentage content of total carbohydrate and a slightly higher content of the hemicellulose fraction than did the leaves from the eared plants. The analyses of the stems of the earless plants and the stems and ears together of the eared plants showed relative differences similar to those from the analyses of entire plants. The total carbohydrate difference of the latter was somewhat more marked than of the former where the leaves were not included.

DISCUSSION

The data reported in this paper are somewhat similar to those reported earlier by Brunson and Latshaw. These authors showed the relative effect of no pollination and incomplete pollination on yield and composition of the corn plant, whereas in the present paper is discussed the influence of a monohybrid character, "earless", on composition and yield within the same selfed line.

The leaves alone or the stems alone of the earless plants weighed more than the corresponding parts of normally eared plants. On the other hand, the total weight of entire eared plants was markedly greater than entire earless plants.

The leaves of the earless plants were not only heavier than the leaves of the eared plants, but they contained a greater percentage composition of nitrogen-free extract and a lesser percentage of crude fiber, thus indicating their superior feeding value. A separate analysis of the stems alone of each class of plants was not made, but it seems probable that if such analyses had been made differences similar to those found in the leaves would have been obtained. The percentages of ether extract in the eared plants were consistently greater in all analyses than in the earless plants, although the differences were not very great (approximately 1%).

Both the chemical analyses and the relative yields indicate that the feeding value per acre of the earless plants is greater than that of the eared plants without the ears. On the other hand, the feeding value per acre of entire eared plants is markedly greater than that of entire earless plants.

The relative feeding value and yields of the two types of plants in this material is of less interest than the distribution of the several carbohydrates studied (Table 4). The entire earless plants were much richer in total sugar and reducing sugar than were the eared plants. Conversely, the latter contained much more starch, evidently stored in the ear, than was contained in the former. In this connection it is interesting to note that somewhat less starch was found in the leaves of the earless plants than in those of the eared plants. This outcome differs from the results of qualitative tests for starch on

other leaves from similar plants. In the latter instance the leaves from the earless plants contained more starch as judged from the iodine test after removal of the chlorophyll (Fig. 1). Apparently in this case there was no tendency to build up a high starch reserve in the leaves of either type of plant. Likewise, the starch content of the stems only from the two earless plants compared with that of the stems and ears together of the two eared plants suggests that the starch reserve in the stems was relatively low in both types of plants. The total sugar was considerably higher in the leaves and in the stems, and the reducing sugar as glucose was much higher in the stems from the earless plants than from the corresponding parts of the eared plants. The earless condition apparently did not interfere with the normal photosynthetic and metabolic processes in the leaves, but owing to the fact that the usual storage organ (the ear) was not present there resulted an accumulation of sugars in the leaves and stems greater than ordinarily occurs. This accumulation was also reflected in the coloring which developed in the earless plants. Similar excess coloring develops in the leaves of normal plants when translocation is interfered with by injury.

The earless plant discussed in this paper is a good example of the profound influence of what apparently is a single gene. The complete absence of an ear is in itself a striking abnormality, but when one considers the whole chain of reactions which may result from this abnormality, the influence of this single gene becomes more striking. The statement has been made that the influence of a particular gene may be determined quite as much by the genotypic complex in which it is functioning as by the gene itself. Here we have an instance of two types of plants which presumably have essentially the same genotypic matrix, except for a single gene, but this single gene both directly and indirectly has a marked influence on growth and development.

SUMMARY

A study was made of the weights and composition of plants and plant parts of normally eared and earless individuals in the same selfed strain of corn. "Earless" behaved as a monohybrid recessive. The stems and leaves of the earless plants weighed more and contained a higher percentage of sugars than did the stems and leaves of the eared plants. With respect to entire plants, the eared individuals weighed significantly more and contained a higher percentage of total carbohydrates and of ether extract than the earless individuals. The percentage of crude protein was somewhat greater in the earless plants.

CHARACTERISTICS OF SOME MORPHOLOGICAL SOLONETZ SOILS OF MINNESOTA[1]

CLAYTON O. ROST[2]

THE occurrence of soils with solonetz morphology in the United States and Canada has been reported by a number of investigators. Carpenter and Storie (2)[3] called attention in 1928 to the presence of such soils in California and reported the mechanical analysis, moisture equivalents, and reactions for representative samples. In 1930 Nikiforoff (10) dealt with the morphology of the profile of this genetic class of soils and described characteristic profiles found in the Minnesota portion of the Red River Valley. Since then, Kelley (5) has studied profiles of such soils occurring in California and Kellogg (7) has dealt with those occurring in western North Dakota. In connection with a study of clay-pan soils, Brown, Rice, and Byers (1) have analyzed a morphological solodized solonetz from Wilkin County, Minnesota, and a member of the Phillips series from northern Montana which probably belongs to the same genetic class. Recently, Murphy and Daniel (8) have contrasted solonetz and normal soils in relation to their erodibility and Ellis and Caldwell (3) have called attention to the occurrence of morphological solonetz soils in Manitoba which have failed to show appreciable quantities of adsorbed Na.

The present study reports some of the physical and chemical characteristics of samples of soil from six representative profiles with solonetz morphology from Wilkin and Traverse counties, Minnesota.

OCCURRENCE OF MORPHOLOGICAL SOLONETZ IN MINNESOTA

Soils with morphological characteristics of solodized solonetz occur in spots of variable size in parts of the Red River Valley in Minnesota but appear to be more common in the southern part. The individual spots are relatively small and make up in the aggregate only a small portion of the total area. They range in size from a rod or less to 4 or 5 rods in diameter and may occur as isolated spots or be relatively numerous in a given area. In one area in Nordick Township, Wilkin County, the spots were so numerous over the distance of three-quarters of a mile as to give the impression of an almost continuous exposure of this kind of soil. The spots appear to lie on the slopes of very slight depressions, but such depressions are usually so slight as to be scarcely visible to the eye.

These soils are associated with the fine-textured members of the Fargo series which occupy the central part of the valley near the Red River where the natural drainage is best developed. It seems prob-

[1]Contribution from the Division of Soils, University of Minnesota and published with the approval of the Director of the Minnesota Agricultural Experiment Station as Paper No. 1394 of the Journal Series. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 12, 1935.

[2]Professor of Soils. The author is indebted to Caroline Chamberlain, Jean Zetterberg, and K. A. Maehl for assistance with chemical analyses.

[3]Figures in parenthesis refer to "Literature Cited", p. 104.

able that following the escape of the main body of water from glacial Lake Agassiz numerous shallow lakes and swampy areas remained and before drainage developed much of this water escaped through evaporation. This partly accounts for the salinization of many of the soils (10). As the natural drainage gradually improved the areas nearest the river where the finest sediments were deposited were affected first and there desalinization has proceeded more rapidly than in the areas nearer the valley edge.

The mean annual precipitation of the area in which profiles were studied is 22.3 inches (56.6 cm) and of this 18.6 inches (47.5 cm) falls during the seven-month period of April to November.

MORPHOLOGY OF THE PROFILE

The characteristic profile of solodized solonetz as displayed in Minnesota has already been described by Nikiforoff (10). The A_1 horizon ranges in thickness from 2 to 8 inches, is black to dark gray in color, and has a poorly developed granular or more frequently a lamellar structure. The boundary between it and the underlying A_2 is irregular. The latter horizon is light gray to ashy gray in color and varies in thickness from a fraction of an inch to as much as 10 inches. It has a finely lamellated, vesicular structure with the upper sides of the plates lighter in color than the lower. Within the same spot the thickness of the A_1 and A_2 horizons may be quite variable.

Between the A_2 and the B horizons the line of demarcation is very sharp. The thickness of the latter varies from 5 to 15 inches, the soil is black, very compact, sticky when wet, and very hard when dry. It has a well-developed columnar structure in the upper part, the columns varying in length from 2 to 5 inches and in width from less than an inch to more than 2 inches. Below them the soil is massive and fractures into rather large irregular lumps.

The C horizon is gray to very dark or olive gray, a silty clay or clay and compact and sticky when wet. The A and B horizons rarely show any effervescence but the C horizon is highly calcareous. Usually the A_1 and A_2 horizons are practically free of soluble salts, but these occur in B and C horizons in varying amounts.

PROFILES STUDIED

Of the six profiles sampled for this study, five (Nos. 1 to 5) were in Wilkin County and one (No. 6) in Traverse County. All profiles displayed morphological characteristics of solodized solonetz and may properly be described as such, although the A_2 horizon of profile 5 consisted of only a thin line of light-colored powder resting on the caps of the columns of the B_1 horizon and was so thin that it could not be sampled.

Where profiles could be sampled in 4-inch layers this procedure was followed but in no case was there a portion of two horizons included in one sample. Since the transition from the B to C horizon is gradual this is ordinarily included in one 4-inch sample and in the present study has been designated the BC transition zone. In all cases the samples represent continuous profiles through the B horizon and in four cases the upper portion of the C horizon as well.

The thicknesses of the different horizons in the six profiles are shown in Table 1. Profile No. 2 was located in the same area of solonetz from which the samples used by Brown, Rice, and Byers (1) were taken, so that their data will be applicable to this case at least.

TABLE 1.—*Horizon thickness of profiles with solodized solonetz morphology.*

Horizon	Inches of profile number						Average, inches
	1	2	3	4	5	6	
A_1........	6	5	4	8*	6	8*	6
A_2........	6	5	4	4	0	4	4
B.........	8*	12†	8*	12†	13†	8*	10
BC.......	4	4	4	—	4	4	4
C‡.......	8	4	10	—	—	12	8

*Sampled in two sections.
†Sampled in three sections.
‡Portion sampled.

METHODS USED

Soluble Salts.—Fifty grams of soil were extracted with CO_2-free distilled water until the leachate was free of sulfates, since preliminary tests had indicated that the alkali salts were mainly sulfates and that gypsum was present in most of the samples. The leachate was evaporated to dryness, the residue carefully ignited to free it of organic matter, cooled, and weighed. It was then extracted with 25 ml. of hot water, filtered rapidly, and washed several times with a few ml. of hot water. The filtrate was evaporated to dryness and the residue dried and weighed. The difference between the two weighings was assumed to represent the $CaSO_4$ present and the last weight the amount of soluble salts or "alkali" salts. The soluble salts were dissolved in distilled water, made up to 250 ml., and the chlorides, bicarbonates, and magnesium determined by the ordinary methods. Since chlorides were absent the magnesium was calculated to $MgSO_4$, the carbonate and bicarbonate to Na_2CO_3, and the difference between the sum of these and the total soluble salts was calculated as Na_2SO_4.

Reaction.—The hydrogen-ion concentration was determined electrometrically, using a bubbling hydrogen electrode.

Texture.—The texture is expressed as the moisture equivalent.

Replaceable bases.—Twenty-five-gram samples of soil were leached with distilled water to the disappearance of sulfates and then with alcoholic (68%) barium chloride, according to the method of Magistad and Burgess (9), until calcium was no longer present in the leachate. The excess barium was precipitated with Na_2CrO_4, filtered off, and the amounts of Ca, Mg, Na, and K in the filtrate determined by standard methods.

RESULTS

SOLUBLE SALTS

In the present study the salts soluble in water have been divided into two groups, *viz.*, (a) calcium sulfate which is not considered as being an alkali, and (b) the alkali salts consisting of the sulfates of magnesium and sodium and carbonates and bicarbonates of sodium. Under the method employed bicarbonates were converted to car-

bonates and determined as such. Ellis and Caldwell (3) have very recently pointed out that the solonetz soils of Manitoba are devoid of sodium carbonate, but that the bicarbonate is one of the dominant ions. In the present study this item was not investigated.

Calcium sulfate (Table 2) is present in all horizons of five profiles but in relatively small amounts until the BC transition zone or C horizon is reached when the amounts increase sharply. The largest amounts are found in the C horizon where nests of gypsum crystals were frequently encountered. The surface layer of soil carried slightly more than the second layer indicating some accumulation at or on the surface due to evaporation. The A_1, A_2, and upper part of the B horizons of profile 2 are essentially free of $CaSO_4$, although in the lower part of the profile it is present in larger quantities than in the other profiles. Above the BC transition the largest amount present in any profile is 515 p.p.m. in the second 4-inch layer of the B horizon of profile 1, while the largest amount present in the C horizon is 2,547 p.p.m. in profile 2.

TABLE 2.—*Amounts of $CaSO_4$ in profiles with solodized solonetz morphology.*

Horizon	p.p.m. of $CaSO_4$ in profile number						Average, p.p.m.
	1	2	3	4	5	6	
A_1........	295	T	210	165	207	82	160
A_2........	25	T	57	97	—*	85	53
B†........	328	T	125	240	129	42	144
	515	185	125	240	127	112	217
	—	175	—	275	335	—	262
BC.......	357	880	1,030	—	1,025	945	845
C........	1,763	2,547	1,200	—	—	2,285	1,949

*Horizon too thin to sample.
†Sampled in 4-inch sections.

The A_1 and A_2 horizons are either free of alkali salts or carry them in only very small amounts (Table 3). In three profiles, Nos. 2, 5, and 6, the upper part of the B horizon is almost free of such salts, but in the remaining three the total salt content increases from the top of the B horizon into the C where it reaches a maximum. The total amounts are variable from profile to profile. Profile 1 carries the largest amount and profile 2 the least, the range in the former being between 1,835 p.p.m. in the upper part of the B and 7,034 p.p.m. in the C horizon, while in the latter it is between 107 p.p.m. in the B horizon (17- to 20-inch layer) and 1,367 p.p.m. in the C.

When the entire profile is considered the soluble salts consist chiefly of $MgSO_4$, while Na_2CO_3 or $NaHCO_3$ are present in smaller amounts and chlorides are absent entirely. The $MgSO_4$ exceeds the Na_2SO_4 in profiles 1, 2, 3, and 6, but for the remaining two the reverse is true.

TEXTURE

In texture the soils of the six profiles vary from silt loams to clays. The moisture equivalents (Table 4) show profile 5 to have the finest texture when the entire profile is considered, the range being between

TABLE 3.—*Alkali salts in profiles with solodized solonetz morphology.*

Horizon	p.p.m. of salts in profile number						Average, p.p.m.
	1	2	3	4	5	6	
				Total Salts			
A_1........	122	0	162	35	129	142	99
A_2........	125	0	198	90	—*	35	90
B........	1,835	0	855	945	204	200	673
	5,250	107	755	3,040	132	490	1,629
	—	277	—	3,240	280	—	—
BC.......	5,420	892	1,905	—	3,880	1,829	2,785
C........	7,034	1,367	2,075	—	—	2,740	3,304
				$MgSO_4$			
B†........	1,015	0	170	176	—	—	—
	2,596	—	127	1,286	—	35	—
	—	62	—	1,392	20	—	—
BC.......	2,620	550	1,120	—	1,459	921	1,334
C........	4,445	1,035	1,493	—	—	1,900	2,218
				Na_2SO_4			
B........	555	0	413	662	—	—	—
	2,322	—	371	1,641	—	322	—
	—	52	—	1,723	68	—	—
BC.......	2,515	181	572	—	1,833	726	1,165
C........	2,375	164	392	—	—	571	876
				Na_2CO_3 and $NaHCO_3$			
B........	265	0	272	107	—	—	—
	332	—	257	140	—	133	—
	—	163	—	125	192	—	—
BC.......	285	161	213	—	88	182	186
C........	214	168	190	—	—	269	210

*Horizon too thin to sample.
†Only total salts determined for the A horizon.

40.0 and 45.7. The values are lowest for profile 6 where they vary between 15.9 for the A_2 horizon and 31.7 for the upper part of the B. There is the same general variation between horizons and subhorizons within all profiles. The moisture equivalent of the A_2 is markedly lower than that of the A_1 with a sharp rise in the upper part of the

TABLE 4.—*Moisture equivalents of profiles with solodized solonetz morphology.*

Horizon	Profile number						Average
	1	2	3	4	5	6	
A_1........	23.7	38.1	32.5	32.8	40.2	27.3	32.4
A_2........	19.5	24.7	23.3	18.3	—*	15.9	20.3
B........	35.9	39.4	30.7	37.0	44.6	31.7	36.5
	35.3	38.2	29.1	36.3	45.7	30.1	35.8
	—	38.3	—	33.2	42.1	—	—
BC.......	31.8	33.9	30.5	—	40.0	29.2	33.1
C........	32.2	33.9	34.4	—	—	30.6	32.8

*Horizon too thin to sample.

B where ordinarily it reaches a maximum for the profile. There is a slight decrease in the lower part of the B followed by further slight decreases in the BC and C horizons. Profile 3 is the only one to present an exception and in this the moisture equivalent for the C is slightly higher than for the B horizon.

The mechanical analysis of samples taken from a profile located in the same spot of solodized solonetz as profile 2 and reported by Brown, Rice, and Byers (1) shows the A_1 and A_2 horizons to be much richer in sands and silt and much poorer in clay than the B horizon, while the latter does not differ much in mechanical composition from the underlying C horizon. The percentages of sands and silt were slightly higher in the A_2 than in the A_1, but the former carried a correspondingly lower percentage of clay. Colloids were highest in the B horizon where they were 58.8% as compared to 53.9% in the C. The lowest percentage, 19.5, was found in the A_2, while for the A_1 it was 27.9%. These data and the moisture equivalents as determined in the present study are in agreement and indicate a marked disintegration of the complex of the A horizon and some eluviation of colloid into the B horizon. The moisture equivalents would indicate eluviation of colloids into the B horizons of profiles 1, 2, 4, and 5 but little, if any, in profiles 3 and 6.

REACTION

The hydrogen-ion concentration of the soil from the six profiles (Table 5) decreases with depth. In all cases the A_1 is acid and wherever this horizon was sampled in two layers (profiles 4 and 6) the lower part was more acid than the upper. The pH values for the former were 6.2 and 5.6 and for the latter 6.6 and 6.1, respectively, for the upper and lower parts. The most acid A_1 horizon is that of profile 1 which has a pH of 5.7 and the least acid are those of profiles 2 and 3 which are pH 6.4. In the majority of cases the reaction of the A_2 horizon is similar to that of the A_1. An exception to this is found in profile 2 where the A_2 horizon showed a pH of 7.6 as compared to 6.4 for the A_1. These figures are in agreement with those reported by Brown, Rice, and Byers (1) who found pH values of 6.3 and 7.5, respectively, for the A_1 and A_2 horizons. The reaction of the soil in the B horizon is usually above pH 7.0, although in the case of profile

TABLE 5.—*Reaction of profiles with solodized solonetz morphology.*

Horizon	pH of profile number						Average, pH*
	1	2	3	4	5	6	
A_1	5.7	6.4	6.4	5.8	5.8	6.3	6.0
A_2	5.9	7.6	6.3	6.2	—†	6.5	6.2
B	7.0	8.2	7.8	6.8	6.9	7.6	7.1
	7.4	8.4	8.1	7.5	7.6	8.2	7.7
	—	8.0	—	7.9	8.1	—	—
BC	8.1	7.7	7.9	—	7.8	8.3	8.0
C	8.1	7.8	8.3	—	—	7.9	8.1

*Calculated from average of cH values.
†Horizon too thin to sample.

4 the upper part of the horizon is very slightly acid, the pH being 6.8. The reaction of the C horizon is in all cases close to pH 8.0 and all samples effervesce freely when tested with dilute acid.

EXCHANGEABLE BASES

Solonetz soils are usually considered to be characterized by a partially destroyed absorptive complex in the eluvial horizon and by a rather high percentage of a monovalent ion or ions, chiefly sodium, in the complex of the illuvial horizon. If it be assumed that the original parent material of the Red River Valley soils was uniform in character, the amounts of exchangeable bases (Table 6) indicate that there has been a very marked modification in the A horizon of the six profiles. The modification has been greatest in the lower part or A_2 horizon as shown by a sharp decrease in the total exchangeable bases. Since the entire horizon is acid there will be some exchangeable hydrogen which, in the present study, was not determined but which would increase the exchange capacity and decrease the percentages of the other bases. The total exchangeable bases rise very markedly in the B horizon, usually reaching a maximum for the profile in the central portion of the horizon. In the C horizon there is again a slight decrease. In respect to the partially destroyed complex in the A horizon the Minnesota profiles appear, then, to meet the solonetz requirement.

TABLE 6.—*Exchangeable bases in M. E. per 100 grams of air-dry soil in profiles with solodized solonetz morphology.*

Horizon	M. E. of exchangeable bases in profile number						Average, M. E.
	1	2	3	4	5	6	
A_1	32.9	33.4	27.1	29.3	30.9	25.7	29.9
A_2	11.5	13.5	17.9	12.6	—	12.6	13.6
B	35.4	47.4	32.2	32.6	40.7	30.4	36.4
	39.3	40.9	35.3	42.1	40.1	32.1	38.3
	—	42.8	—	39.0	41.7	—	—
BC	41.2	39.0	35.6	—	43.1	32.4	38.4
C	38.8	36.7	40.2	—	—	26.1	35.4

According to Gedroiz (4), a partially destroyed eluvial horizon is evidence of an earlier stage, that of salinization with soluble salts of sodium. In the six profiles both exchangeable Na and K are present in very small amounts and, in the present stage of development, appear to be relatively unimportant (Table 7 and Fig. 1). Exchangeable Mg, on the other hand, is present in relatively large amounts and is the most prominent ion of the absorptive complex.

In the A_1 horizon the amounts of exchangeable Mg in four of the six profiles (Nos. 1, 3, 4, and 6) are not exceptionally high and the ratio of Ca to Mg is not far below that found for the upper part of the A horizon of the undegraded chernozems of the same area. The percentage of exchangeable Ca in the A_1 horizon of the four profiles varies between 66.1 (profile 6) and 71.9 (profile 3) of the total bases

TABLE 7.—*Distribution of exchangeable Ca, Mg, Na, and K in profiles with solodized solonetz morphology.*

Horizon	Percentage in profile number						Average, %
	1	2	3	4	5	6	
				Calcium			
A_1	66.9	44.6	71.9	68.5	41.1	66.1	59.9
A_2	55.7	29.6	43.0	50.8	—	60.6	47.9
B	25.1	15.2	22.4	22.7	28.8	32.9	24.5
	32.8	19.1	29.5	16.6	27.9	44.2	28.3
	—	28.5	—	19.0	30.2	—	—
BC	61.4	60.3	45.2	—	44.1	52.2	52.6
C	71.6	78.8	53.2	—	—	48.3	63.0
				Magnesium			
A_1	31.3	52.7	26.2	27.2	54.7	30.6	37.1
A_2	40.8	58.5	48.6	44.4	—	35.1	45.5
B	70.9	75.7	70.8	72.7	64.6	62.5	69.6
	65.9	79.2	65.7	78.4	68.8	53.3	68.5
	—	68.3	—	76.2	66.9	—	—
BC	36.1	38.2	52.2	—	52.7	47.2	45.3
C	26.8	20.4	45.0	—	—	48.2	35.1
				Sodium			
A_1	0.6	1.2	1.1	2.3	2.6	1.2	1.5
A_2	1.7	6.7	7.8	4.0	—	3.2	4.7
B	3.1	5.5	5.6	3.0	4.7	2.3	4.0
	1.0	1.7	4.0	4.0	3.0	1.5	2.5
	—	1.6	—	3.8	2.1	—	—
BC	1.0	0.5	0.9	—	2.1	0.6	1.0
C	0.8	0.0	0.5	—	—	0.1	0.4
				Potassium			
A_1	1.2	1.5	0.8	2.0	1.6	2.1	1.5
A_2	1.7	5.2	0.6	0.8	—	1.1	1.9
B	0.9	3.6	1.2	1.6	1.9	2.3	1.9
	0.3	—	0.8	1.0	0.3	1.0	0.7
	—	1.6	—	1.0	0.8	—	—
BC	1.5	1.0	1.7	—	1.1	—	1.1
C	0.8	0.8	1.3	—	—	3.4	1.5

determined, while for Mg the variation is between 26.2 and 31.3%. The ratio of Ca to Mg varies from 2.16 (profile 6) to 2.74 (profile 3). The percentage of exchangeable Mg in the A_1 horizon of the two remaining profiles, Nos. 2 and 5, is much higher, comprising 52.7 and 54.7, respectively, of the total bases and having Ca:Mg ratios of 0.85 and 0.75. The highest percentage for Na in the A_1 horizon is 2.6 in profile 5, while for K it is 2.1 in profile 6. The average percentages of exchangeable Ca and Mg in the A_1 horizon of the six profiles are 59.2 and 37.4, respectively, while Na and K each constitute 1.5%.

When the A_2 horizon is reached, the percentage of Ca in the complex falls perceptibly and varies between 29.6 and 60.6 of the total bases, while the percentages of Mg, Na, and K rise. The greatest increase in Mg is in profile 3 where the percentage rises from 26.2 in the A_1 to 48.6 in the A_2 horizon, and least in profile 6 where the

increase is from 30.6 to 35.1%. When the average amounts of exchangeable bases are considered, it is seen that the percentages of Ca and Mg are almost identical, *viz.*, 47.9 and 45.5. The increase in exchangeable Na and K is on the average from 1.5% for both in the A_1 to 4.7 and 1.9%, respectively, in the A_2.

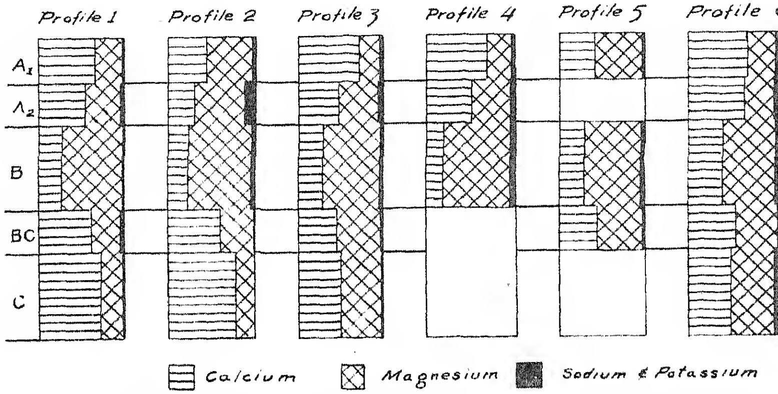

FIG. 1.—Diagram showing percentages of exchangeable bases in the different horizons of the six profiles studied.

As would be expected there is a very sharp increase in the total amount of exchangeable bases in the B horizon. The increase in the upper part of the horizon is due almost entirely to exchangeable Mg as there is a relatively small increase in the amount of exchangeable Ca, and while the amounts of Na and K in some cases are more than double those found in the A horizon, they still constitute, on the average, only 6% of the exchangeable bases. The average of total bases is 36.4 M. E. and of this Ca constitutes 24.5 and Mg 69.6%. In the lower part of the B horizon the Ca increases considerably, the Mg, Na, and K decrease somewhat and the sum of total bases rises slightly. Exchangeable Mg still constitutes from two-thirds to three-fourths of the exchangeable bases in all but profile 6 where it is slightly over half, 53.3%. The highest percentage of exchangeable Na is found in profile 3 where the average for the horizon is 4.8. Considering the amounts of exchangeable Mg and Na in the B horizon of all profiles, Na could not be considered as a dominant ion and in this respect the soils fail to meet the chemical requirement for solonetz classification. When the transition layer, BC, is reached the amount of total bases remains the same as in the lower part of the B, but there is a marked increase in exchangeable Ca and a corresponding decrease in exchangeable Mg. On the average the Ca rose to 52.6% of the total exchangeable bases, while the Mg fell to 45.3%. There was a decrease in exchangeable Na but K remained practically constant.

The sum of the total bases decreases slightly on the average when the C horizon is reached. In three of the four profiles for which samples were analyzed there was a distinct increase in exchangeable Ca. In

one (profile 6) both the amount and percentage decreased. The average for the horizon in the four profiles is 63.0%, an increase of 10% over the average for the BC transition layer, while there was a decrease of 10% in exchangeable Mg and a decrease from 1.0 to 0.4% of exchangeable Na.

It is to be noted that insofar as exchangeable bases are concerned the B horizon of profile 5, in which the A_2 horizon is only rudimentary, is very similar to that of the other horizons. The A_1 however carries a higher percentage of exchangeable Mg than profiles 1, 3, 4, and 6, but is similar to that of profile 2 where the A_2 horizon is 5 inches thick.

The chemical analysis of the soil by Brown, Rice, and Byers (1) likewise indicates a marked disintegration of the absorptive complex of the A horizon. When their data are calculated to the basis of material free of volatile matter, carbonate, and sulfate, this is very evident (Table 8). In making such calculations for the C horizon, where free carbonates of both lime and magnesium occur, their figure of 71.5% SiO_2 was used as a basis. In the others the carbonates and sulfates have been calculated as $CaCO_3$ and $CaSO_4.2H_2O$.

TABLE 8.—*Chemical analysis of Fargo sample (solodized solonetz) calculated on the basis of material free of volatile matter, carbonate, and sulfate from the data of Brown, Rice, and Byers (1).*

Horizon	Depth, in.	SiO_2 %	Fe_2O_3 %	Al_2O_3 %	MgO %	CaO %	K_2O %	Na_2O %
A_1	0–6	80.41	2.72	10.60	1.21	0.76	1.87	1.06
A_2	7–10	82.46	3.01	8.33	0.76	0.70	2.00	1.41
B	12–20	71.41	5.63	15.78	2.55	0.32	1.98	0.81
C	32–48	71.50	5.67	17.10	—	—	2.54	0.97

It is seen that the percentage of silica is markedly higher in the A than in the B horizon, while the alumina, iron, and magnesia are lower. The soda is distinctly higher, but the potash shows little variation. The percentages of constituents in the B horizon are in the main quite similar to those in the C. This is especially true for silica, iron, and soda, but for alumina and potash the percentages are slightly higher in the C horizon. This similarity between the B and C horizons has led Brown, Rice, and Byers to conclude that the B horizon is essentially impermeable to water and that the eluviated constituents from the A horizon have been carried away by lateral erosion through the A_2 or along the top of the B horizon. From the data it is not clear as to the destination of the constituents removed from the A horizon, although there would appear to be some question as to the impermeability of the B horizon. The latter is essentially free of carbonates and if an original uniform parent material is assumed these must have been removed by percolating water. The fact that soluble salts are much lower in the B horizon than in the C would indicate some downward movement of water, although in order to maintain this condition the downward movement would only need to be great enough to exceed the upward movement. The columnar structure and vertical cleavage would also tend to facilitate the movement of water into the B horizon.

Recent studies by Russian investigators (11, 13, 14), mentioned later, indicate that magnesium in the complex has only a limited effect as a peptizer and that the filterability of soils, the complex of which has been saturated with magnesium, resembles more nearly those saturated with calcium than those saturated with sodium. In the present study it was observed that in the filtering operation for the removal of soluble salts, the samples from the B horizon filtered more slowly than those of the A, but less difficulty was encountered than had been anticipated and that differences in filterability between the B and C horizon samples were not great.

DISCUSSION

The six profiles appear to possess all the morphological requirements of solodized solonetz, including the destroyed absorptive complex of the A horizon and the dense, black columnar B horizon. The exceptional features are the very low percentages of sodium and the very high percentages of magnesium in the exchange complex of the B horizon, calcium and magnesium ordinarily accounting for 90% of the total exchangeable bases and magnesium constituting one-half to two-thirds of them. Nikiforoff (10), who first studied the morphology of the profiles in the field, classified them as solonetz and assumed that exchangeable sodium was a dominant ion in the complex.

The few studies of solonetz and solonetz-like soils in the United States that include determinations of exchangeable bases show that sodium occupies a less prominent place in the complex than might be anticipated and that exchangeable magnesium makes up a rather high percentage. The exception to this is the Oklahoma soils reported by Murphy and Daniel (8) in which exchangeable sodium is a dominant ion. The maximum and minimum percentages of exchangeable magnesium reported in the different studies are shown in Table 9. The highest percentage, 76, was found in Minnesota profile 4 and the next highest, 66, in the San Luis Obispo sample reported by Kelley (5), while the lowest, 15, was in the exposed B horizon of farm E at Stillwater, Oklahoma. The percentage of exchangeable Na was highest, 56, in the same Oklahoma sample and lowest, 2, in Minnesota profile 6.

Whether or not the characteristic morphology of solonetz soils develops under the influence of Mg ions in the exchange complex does not appear to be established. As suggested by Kelley and Shaw (6), there is a possibility that such soils, even though Mg comprises a high percentage of the exchangeable bases, may have passed through a stage in which sodium was one of the dominant ions of the absorptive complex. A number of studies dealing with the effect of exchangeable Mg in the complex have appeared recently. Sushko and Sushko (13) saturated kaolin with Ca, Mg, and Na and determined the rate of filtration or permeability and found that the effectiveness of the ions might be expressed relatively as 100:70:1, respectively. By saturating solonetz soils containing Na with Mg they found the permeability to be markedly increased and conclude that Mg in the complex has only a limited effect as a peptizer and in this rôle stands

TABLE 9.—*Maximum and minimum amounts of exchangeable Mg reported for solonetz and solonetz-like soils of the United States.*

Description	Reported by	Percentage of total bases			
		Mg	Ca	Na	K
	California				
San Luis Obispo	Kelley	66	27	6	1
Pasa Robles	Kelley	40	49	10	1
	North Dakota				
Profile 11*	Kellogg	47	39	12	2
Profile 9	Kellogg	24	64	10	2
	Oklahoma				
Stillwater farm A†	Murphy & Daniel	27	32	37	4
Stillwater farm E	Murphy & Daniel	15	24	56	5
	Minnesota				
Profile 4	Author	76	19	4	1
Profile 6	Author	58	38	2	2

*Calculated from the sum of exchangeable Ca, Mg, Na, and K.
†1- to 12-inch section of exposed B horizon.

nearer Ca than Na and accordingly does not impart solonetz properties to the soil. They visualize the exchange mechanism as consisting of complexes relatively saturated with Mg, held in the surface very tightly to form a new type of Mg complex. This complex in turn might be dispersed by the action of Na and reflocculated by the removal of the Na by leaching, the latter being carried away before the more difficultly removable Mg. Such Mg would be able to play a part in exchange only after the Na has been removed.

Similarily, Uvarov and Kamlov (14) found that by saturating the illuvial horizon of four solonetz soils with Ca, Mg, and Na, the permeability was increased most by Ca, and that while Mg was not as effective, there was a very marked improvement as compared to the Na-saturated soil. The Mg was most effective as a coagulent in the soils having the most strongly developed solonetz properties. Saturation with Mg raised the moisture equivalent and increased dispersion somewhat, but in general the behavior resembled that of the Ca-saturated complex more closely than that of the Na-saturated one. From this they conclude that exchangeable Mg does not have much influence upon the solonetz character of soils.

Shavrygin (11) reports a study very similar to the two just mentioned in which the exchange complex of solonetz soils was saturated with Ca, Mg, and Na and the soils then studied with respect to permeability, hygroscopicity, water absorption, maximum water capacity, capillary rise of water, stickiness, degree of dispersion, and heat of wetting. His data show as in the other studies that in its effect on the soil Mg falls between Ca and Na. Since it modified the physical properties of the soil analogous to the absorption Na, although in a much less degree, it was concluded that the absorption

of Mg may control the solonetz characteristics if the latter are governed by such physical properties as were studied.

Kelley and Shaw (6, 12) have raised the question as to what constitutes a solonetz. The matter appears to resolve itself into the question of whether the morphological or chemical features or both are to be used as criteria. Ellis and Caldwell (3) suggest that a combination of both be used and that such designations as sodium solonetz and magnesium solonetz be employed. The present study demonstrates the occurrence of soils with morphology typical of solodized solonetz and having little or no greater amounts of exchangeable sodium present in the complex of the illuvial horizon than found in normal soils but having large amounts of exchangeable magnesium. If the suggestion of Ellis and Caldwell were followed they would be classed as magnesium solonetz. However, the question of whether or not these and other soils of similar character have developed under the influence of the magnesium ion in the absorptive complex has not been definitely answered.

SUMMARY

Samples from six soil profiles located in the southern part of the Minnesota portion of the Red River Valley and having morphological characteristics of solodized solonetz were examined. The soils were fine textured varying from silt loams to clays. The A horizon was found to be essentially free of soluble salts, but these were present in the B horizon where they increased in amount downward to reach a maximum in the C horizon. The A_1 horizon was acid in reaction in all cases and the A_2 in all but one case, while the B and C horizons were alkaline.

The total exchangeable bases decreased sharply in the A_2 horizon and rose again very sharply in the B horizon where, on the average, they reach a maximum and where they exceeded somewhat the amounts found in the C horizon. The exceptional features of the profiles were the very low amount of exchangeable sodium and the very high amounts of exchangeable magnesium found in the complex of the B horizon. Ordinarily the calcium and magnesium accounted for 90% or more of the exchangeable bases and of this the exchangeable magnesium comprised one-half to three-fourths. The average percentage of exchangeable sodium in the same horizon was approximately 3.0 and was lower than would be expected if the soils were classified as solonetz. Those for exchangeable magnesium, on the other hand, were much higher than would be anticipated. This situation is contrary to the general conception of the development of solonetz soils under the influence of exchangeable sodium in the absorptive complex of the B horizon, but it is pointed out that the present condition does not preclude an earlier stage of development when sodium may have been a dominant ion in the complex.

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THE DIFFERENTIAL INFLUENCE OF CERTAIN VEGETATIVE COVERS ON DEEP SUBSOIL MOISTURE[1]

H. E. Myers[2]

THE depletion of subsoil moisture by alfalfa has been studied during the preceding decade at both the Nebraska and Kansas Experiment Stations[3] where rainfall is frequently a limiting factor in crop production. The results obtained are so conclusive as to warrant the generalization that alfalfa growing on the soil for several years under conditions of limited rainfall reduces the available supply of moisture in the subsoil to depths much below the normal penetration of seasonal precipitation. Studies on this general problem have been continued by the Kansas Experiment Station. One phase which is herein reported deals with the influence of different legumes and non-legumes on subsoil moisture.

PLAN OF EXPERIMENT

For this investigation three adjoining series of plats located on the agronomy farm together with a nearby native grass pasture are utilized. Two of the series are devoted to rotations of legume, corn, and kafir (half the plat being planted to each), oats, and wheat, while the third is used for a rotation of corn, oats, and wheat. The legumes and length of time which they remain on the soil are as follows: Alfalfa, 2 years; biennial white sweet clover, 2 years; biennial white sweet clover, 1 year; and soybeans, 1 year. The legumes grown for 2 years as well as those grown for 1 year are compared directly and occupy adjacent duplicate plats. The experiment has been of sufficient duration that the rotation on all plats has now passed through one cycle and the second cycle is either completed or nearing completion, consequently a legume has been on each plat for either one or two periods. The years when legumes occupied the plats together with the annual rainfall for those years are shown in Table 1.

While the crop history of the cultivated land under consideration is not complete, it is thought that neither alfalfa nor sweet clover have been grown on the area previous to the present experiment. This conclusion is supported by the soil moisture data collected in this study. The moisture differences that occur between plats together with the regularity of these occurrences on duplicate plats strongly suggest that the subsoil moisture had not previously been depleted.

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[2]Assistant Professor of Soils: The author is indebted to Dr. M. C. Sewell, formerly of this department, for starting much of the field work which made this investigation possible and also to coworkers who have given helpful criticisms during the progress of the work and the preparation of the manuscript.

[3]Duley, F. L. The effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron., 21: 224–231. 1929.

Kiesselbach, T. A., Russel, J. C., and Anderson, A. The significance of subsoil moisture in alfalfa production. Jour. Amer. Soc. Agron., 21: 241–268. 1929.

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TABLE 1.—*Annual rainfall for those years when legumes occupied the various plats.*

Year	Legumes 2 years			Legumes 1 year			
	Plats 1, 2, 11, 12	Plats 5, 6, 15, 16	Plats 7, 8, 17, 18	Plats 1, 2	Plats 3, 4	Plats 5, 6	Plats 7, 8
1927	37.45	——	——	37.45	——	——	——
1928	34.19	——	——	——	——	——	34.19
1929	——	——	33.63	——	——	33.63	——
1930	——	34.18	34.18	——	34.18	——	——
1931	——	38.75	——	38.75	——	——	——
1932	23.93	——	——	——	——	——	23.93
1933	21.94	——	——	——	——	21.94	——
1934	——	——	19.38	——	19.38	——	——
1935	——	——	16.81*	——	——	——	——

*Rainfall until August 1, a deficit of 2.91 inches. The average annual rainfall over a 43-year period has been 31.49 inches.

The soil was sampled by means of a tube equipped to go to a depth of 25 feet. Not all plats were studied this deep, since normally samples were taken only slightly deeper than the dry layer. Several pairs of plats scattered the length of each series were studied so that a direct comparison between two legumes could be made. Some of the plats sampled represent duplicate treatments. Three individual samples were taken from each plat. The data as presented constitute an average of these three readings unless otherwise stated. The samples were taken in foot sections on which both the moisture and moisture equivalent determinations were made. The moisture was determined by driving off the water at 110 C, while the moisture equivalent was determined by the centrifugal method. The samples that had been dried for the moisture determination were used for finding the moisture equivalent. It is recognized that the previous drying probably altered the true moisture equivalent, but since all samples were treated in the same manner, it is believed that the value of the results is not lessened.

The soil moisture was expressed finally as percentage of the moisture equivalent. This gives a figure which Conrad and Viehmeyer[4] designate "relative wetness". It was found that this method of expression overcame to a large extent differences due entirely to texture. This procedure was necessary because of the very abrupt and frequent changes in texture at the lower depths which made actual moisture figures too confusing to permit of satisfactory interpretation.

RESULTS OF EXPERIMENT

The experimental results are reported in Tables 2 and 3 and are presented graphically in Figs. 1 and 2.

In the interpretation of the data, a soil moisture content of 55% or less of the moisture equivalent is considered dry (at or near the minimum point of exhaustion), while soil with a moisture content of 70% or more of the moisture equivalent is considered to have been unaffected by crop removal.

The data in Table 2 make possible direct comparison of the differential effect on soil moisture of alfalfa and sweet clover both of which are allowed to grow continuously through two seasons. Data from

[4]CONRAD, JOHN P., and VIEHMEYER, F. J. Root development and soil moisture. Hilgardia, 4: 113–134. 1929.

TABLE 2.—*Moisture in the soil following alfalfa and sweet clover (each 2 years) expressed as percentage of the moisture equivalent.**

Depth of soil, feet	Plat number																	Non-legume rotation†
	1, 2 yrs. sweet clover	2, 2 yrs. alfalfa	5, 2 yrs. sweet clover	6, 2 yrs. alfalfa	7(a),† 2 yrs. sweet clover	8(a),† 2 yrs. alfalfa	7(b),‡ 2 yrs. sweet clover	8(b),‡ 2 yrs. alfalfa	11, 2 yrs. sweet clover	12, 2 yrs. alfalfa	15, 2 yrs. sweet clover	16, 2 yrs. alfalfa	17(a),† 2 yrs. sweet clover	18(a),† 2 yrs. alfalfa	17(b),‡ 2 yrs. sweet clover	18(b),‡ 2 yrs. alfalfa	Native grass sod§	
1	68.9	66.5	45.7	51.6	48.5	51.8	44.8	83.2	66.0	54.5	57.6	57.3	59.2	55.7	45.9	42.8	78.3	80.7
2	68.3	67.5	60.9	63.0	59.2	57.8	59.0	58.5	67.8	62.3	56.8	66.8	72.0	54.3	54.7	55.3	55.8	83.8
3	65.5	62.8	58.8	60.7	53.9	51.5	58.7	55.2	74.3	62.4	52.9	62.2	64.7	50.3	46.4	54.1	56.1	76.4
4	69.1	59.6	58.4	63.0	51.6	50.1	51.4	52.5	70.8	54.1	52.1	63.0	60.6	51.3	49.3	48.6	55.6	66.5
5	69.3	61.6	57.6	59.7	54.0	53.8	53.6	52.5	58.4	51.2	60.1	57.4	59.4	54.1	50.4	47.9	50.6	64.4
6	59.5	52.9	59.0	60.4	60.5	57.5	55.5	51.1	56.6	54.1	56.3	54.4	67.1	54.7	52.5	46.4	56.6	67.1
7	54.6	53.8	67.1	57.8	**68.9**	**64.5**	53.9	53.0	51.9	60.6	56.9	57.4	**69.4**	55.6	51.4	52.6	**64.6**	**65.1**
8	55.7	54.2	**69.4**	59.1	77.5	71.3	55.3	57.2	50.4	65.7	54.7	59.5	70.8	55.0	57.3	52.0	71.3	72.1
9	55.7	53.3	74.2	60.0	84.1	76.5	56.6	55.1	53.1	52.7	57.6	58.8	71.0	52.7	52.7	50.4	70.6	76.5
10	54.9	52.2	77.8	59.9	84.4	78.6	53.7	52.3	53.5	48.7	61.0	58.5	74.8	53.3	54.8	55.2	71.4	81.8
11	54.0	50.9	80.7	60.9	80.9	79.9	56.1	53.3	48.4	49.9	**66.9**	60.5	74.8	53.3	51.8	53.2	71.5	78.6
12	56.4	49.9	81.9	68.9	81.1	77.1	64.6	50.6	47.3	46.6	72.2	59.1	75.2	53.4	—‖	50.9	73.1	84.1
13	57.7	49.3	79.6	60.6	79.4	75.9	59.5	51.2	52.4	46.3	75.6	**65.5**	77.9	54.0	58.0	50.2	76.6	83.6
14	**61.9**	48.9	82.3	61.1	83.8	85.3	67.0	52.4	**58.2**	45.2	82.1	70.6	76.6	55.5	**62.0**	55.0	78.6	88.7
15	74.7	45.9	83.2	62.0	88.0	88.9	**65.0**	**57.6**	71.6	44.5	85.5	78.7	79.7	60.3	83.3	51.2	83.9	94.2
16	70.7	59.2	81.7	**68.7**	88.7	84.7	74.9	75.4	79.6	51.5	82.5	80.8	83.3	**68.9**	76.8	48.9	81.9	81.1
17	79.0	42.3	87.3	83.9	97.3	88.7	89.0	87.6	97.4	**65.2**	89.3	88.6	92.8	72.9	90.9	**49.8**	85.6	86.6
18	78.5	47.0	91.3	79.1	99.6	93.3	90.4	95.9	102.8	95.0	94.2	96.0	94.2	77.0	92.5	86.0	84.8	87.8
19	—	**67.2**	—	—	—	—	—	80.4	—	89.3	—	—	—	94.3	89.4	86.6	86.3	86.1
20	—	92.0	—	—	—	—	—	72.1	—	92.8	—	—	—	—	—	—	87.8	93.6

*The paired plats are to be compared directly since the legumes occupied the two areas during the same years. Replication begins with No. 11 which is the duplicate of No. 1, plat 12 the duplicate of plat 2, etc.

†Average of two samples. Plats 7a, 8a, 17a, and 18a taken after the alfalfa and sweet clover had occupied the area for 2 years, but before the second seeding of these crops had become established.

‡Reading from one sample taken near the end of the second 2-year period of alfalfa and sweet clover.

§Average of four samples.

‖Lost.

an area devoted to a nonlegume rotation and from an area of native grass sod are included for comparison. In neither instance has the soil been reduced to dryness below the sixth foot. The results are shown graphically in Figs. 1 and 2.

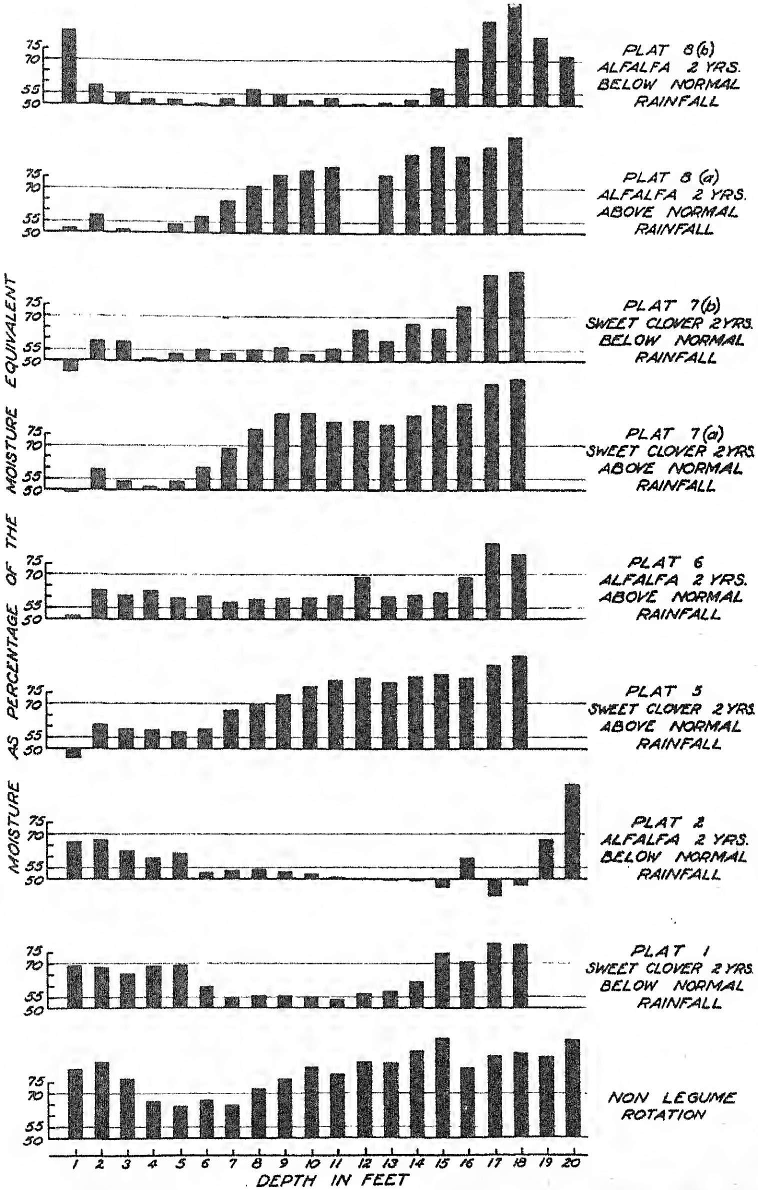

FIG. 1.—The comparative effect of alfalfa, sweet clover, and annual non-legumes on deep subsoil moisture.

The soil moisture in both of the duplicate sweet clover plats, 1 and 11, was reduced below 70% of the moisture equivalent down to the fifteenth foot, while the adjoining alfalfa plats, 2 and 12, show reduction to the twentieth and eighteenth foot, respectively.

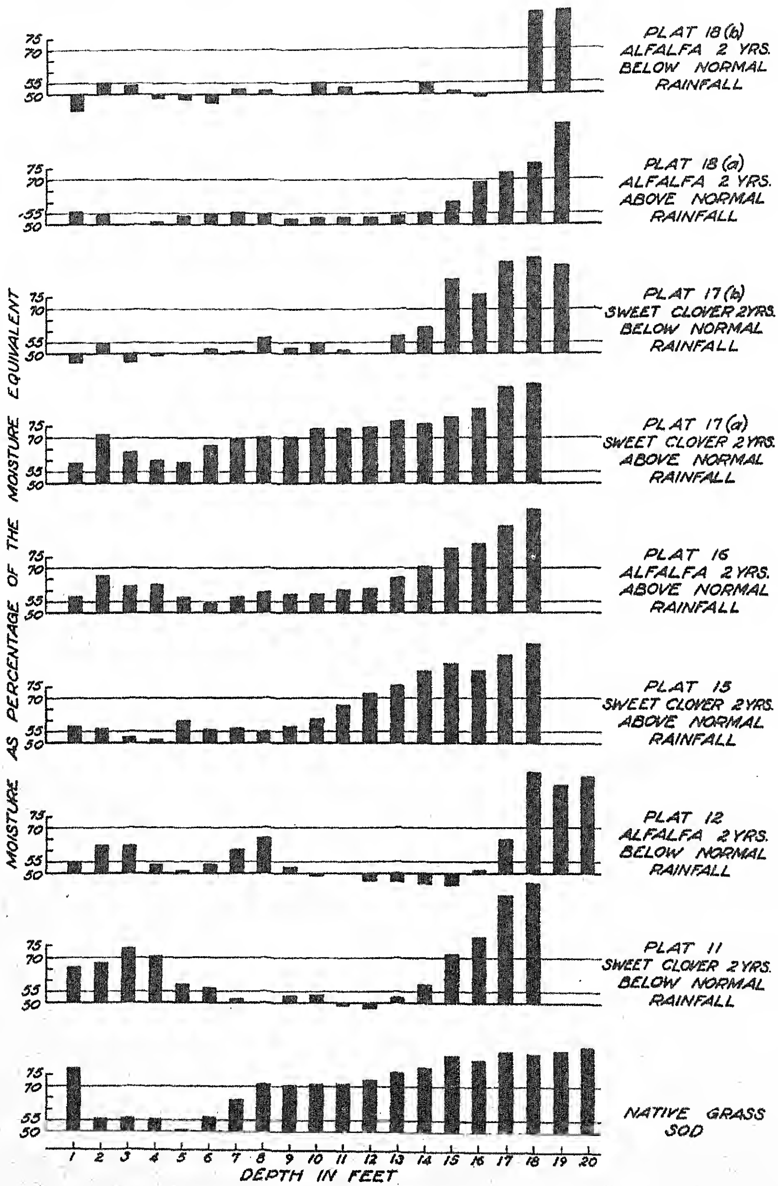

FIG. 2.—The comparative effect of alfalfa, sweet clover, and native grass sod on deep subsoil moisture.

TABLE 3.—*Moisture in the soil following sweet clover and soybeans (each 1 year) expressed as percentage of the moisture equivalent.**

Depth of soil, feet	Plat 1†, 1 year sweet clover	Plat 2‡, 1 year soy-beans	Plat 3, 1 year sweet clover	Plat 4, 1 year soy-beans	Plat 5‡, 1 year sweet clover	Plat 6‡, 1 year soy-beans	Plat 7, 1 year sweet clover	Plat 8, 1 year soy-beans	Non-legume rota-tion
1	73.3	77.3	56.9	70.6	66.7	75.2	74.9	67.4	83.2
2	71.1	75.0	57.8	62.5	57.0	60.5	64.8	62.5	75.6
3	60.9	70.6	56.5	55.9	53.0	56.6	59.8	62.3	67.9
4	60.8	69.9	57.1	52.1	52.1	53.6	60.7	63.0	70.4
5	67.6	65.1	58.8	54.2	51.2	55.0	60.6	66.4	72.8
6	69.7	73.0	58.7	57.4	49.4	60.0	59.2	66.0	72.5
7	69.6	73.4	58.8	64.8	54.6	65.6	50.3	68.2	78.9
8	71.7	74.0	52.9	73.9	54.8	73.0	52.7	67.8	85.9
9	74.4	76.4	55.5	77.1	57.4	79.7	60.6	65.5	84.2
10	77.5	84.7	64.6	79.2	70.3	84.9	70.4	81.6	86.1
11	—	—	68.4	—	—	—	85.3	—	88.5
12	—	—	87.6	—	—	—	87.0	—	91.8

*The paired plats are to be compared directly since the legumes occupied the two areas during the same year.
†Two cores only.
‡One core only.

In plats 5 and 15 the moisture was reduced much less than in plats 1 and 11. In plat 5 there was some reduction to the ninth foot but only slight reduction below the sixth foot, while in plat 15 there has been a lowering of the moisture content to the twelfth foot. The adjoining alfalfa plats, 6 and 16, show some reduction to the seventeenth and fourteenth foot, respectively. However, it can be noticed that the moisture reduction has not been as severe on these plats as on plats 2 and 12. The data indicate that on these areas the alfalfa has not reduced the moisture to the minimum point of exhaustion for the crop. On the sweet clover plats, 7 and 17, the moisture, during the first period of legume cover, has not been reduced below the seventh foot. On the corresponding alfalfa plats, 8 and 18, the reduction has been to the eighth and seventeenth foot, respectively.

When the sweet clover occupied plats 7 and 17 the second time a marked change was brought about in the deep soil moisture. During this period the reduction extended to a depth of 15 and 14 feet, respectively. During the same period the alfalfa on plat 8 reduced its moisture to the sixteenth foot. There is only a slight change in the moisture data for plat 18 for the two periods and the difference that does exist is probably due to sampling variation since it is doubtful if the roots of the second alfalfa crop could penetrate the dry layer formed by the first crop.

From the data presented it appears that sweet clover when allowed to make continuous growth for 2 years may, under certain environmental conditions, reduce the subsoil moisture to or close to the minimum point of exhaustion to a depth much below the normal seasonal penetration of rainfall. The maximum reduction under the conditions of this experiment has been 14 feet. This is in contrast to the results reported by Kiesselbach, Anderson, and Russel.[5] They

[5]*Loc. cit.*

state that "under sweet clover and red clover there was no significant moisture change below the sixth foot throughout the 5-year period."

In general, the depth of water removal for the experiment herein reported has not been as great with sweet clover as with alfalfa, but the apparent difference may be due to the variation in length of time the two crops occupy the soil. The alfalfa has the advantage of being established in the fall and also of growing after the sweet clover matures the second year. However, from a practical consideration the sweet clover is not as efficient in the utilization of deep subsoil moisture as the alfalfa, since the latter, which normally remains on an area for several years, will utilize the moisture to a considerably greater depth than the sweet clover. Sweet clover will possibly produce a dry layer of such magnitude as to make it impossible later for alfalfa to utilize the moisture at greater depths, whereas if the sweet clover were not included in the rotation this moisture could be used by the alfalfa.

The differential effect of both alfalfa and sweet clover on subsoil moisture in different seasons appears to be a direct function of the rainfall. In those years of marked deficiency of rainfall subsoil water was removed by both legumes to considerable depth, while on the other hand, during years of high rainfall deep subsoil moisture was depleted only slightly by both crops.

The data presented in Table 3 and Fig. 3 make possible a direct comparison of the influence of annual crops, including soybeans, 1 year sweet clover, and no legume, on subsoil moisture. On none of the soybean plats (2, 4, 6, and 8) has the moisture below the sixth foot been reduced to 55% of the moisture equivalent. While there has apparently been a reduction in the moisture by this crop, in some instances through the ninth foot, the reduction has probably not been of such magnitude as to prevent the roots of subsequent crops from penetrating this area.

On plats 3, 5, and 7 which supported sweet clover the soil has been reduced to near the minimum point of exhaustion through the ninth and eighth foot levels, respectively. There was apparently little or no reduction in the moisture content of the other sweet clover plat (plat 1). This probably was due to the more favorable rainfall during the periods of legume growth. A sample on plat 1 taken September 16, 1935, when sweet clover was again occupying the plat, indicated an almost complete drying to the eighth foot and a marked reduction through the ninth foot. The precipitation in the summer of 1935 was below normal.

From a practical point of view the reduction in subsoil moisture by 1 year of sweet clover may be of some importance when alfalfa production is to follow. This will probably be true if unfavorable rainfall conditions prevail during the interval intervening between the two crops. On the other hand, the depth to which water has been removed is not sufficiently great to preclude the possibility of renewal by seasonal rainfall. Penetration of water in the fall of 1935 on plat 5 reached into the ninth foot by November 1 which has eliminated the definitely dry layer that previously existed. This plat was plowed after oats harvest in preparation for wheat. On plat 3

where kafir was growing the penetration of moisture has been only to the eighth foot. In the latter plat a dry layer 2 feet in thickness remains.

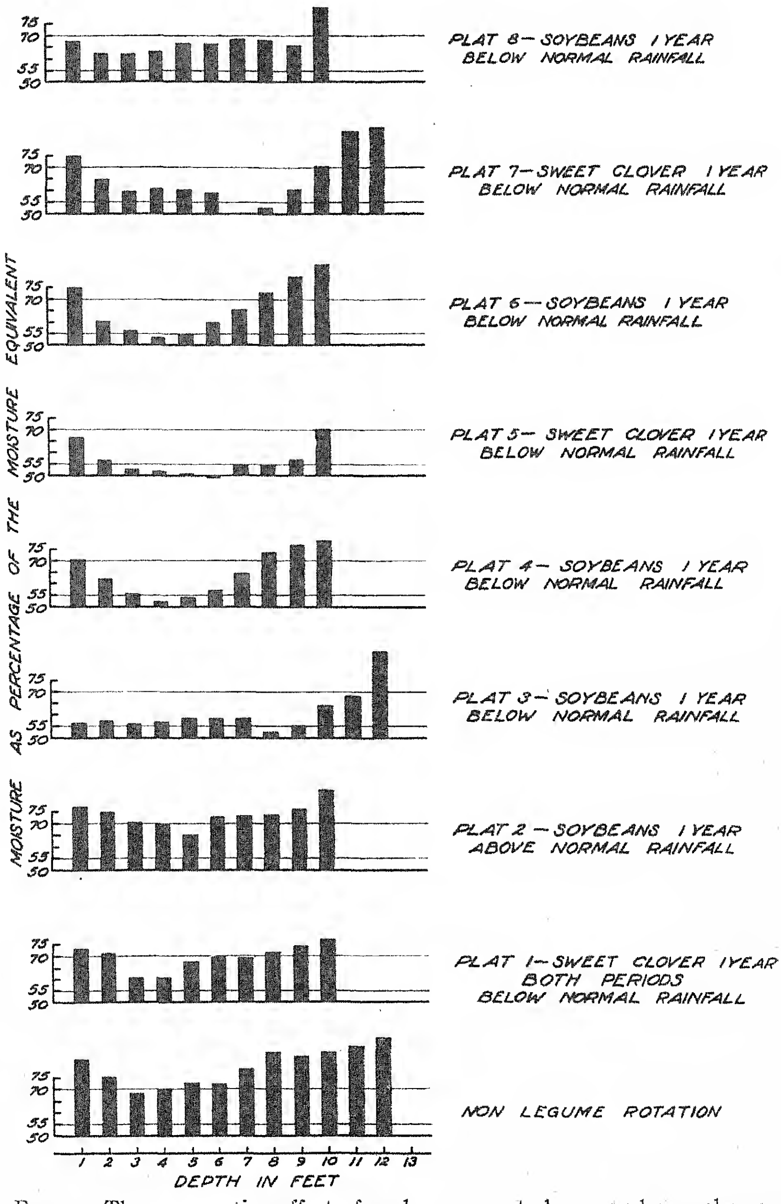

FIG. 3.—The comparative effect of soybeans, sweet clover, and annual non-legumes on deep subsoil moisture.

(Note: The legend for plat 3 should read sweet clover rather than soybeans.)

CONCLUSIONS

Sweet clover grown continuously on soil for two seasons under the condition of this experiment has reduced the subsoil moisture in certain instances to a maximum depth of 14 feet. The data indicate that a reduction approaching the minimum point of exhaustion has extended into the thirteenth foot section.

One year's growth of sweet clover in certain cases has reduced the moisture to near the minimum point of exhaustion to a maximum depth of 9 feet.

Soybeans growing for one season have not resulted in the development of a dry layer below the sixth foot in any plat included in this study.

The depth of the moisture reduction by alfalfa and sweet clover has been governed largely by the rainfall during the period when the legume occupied the soil.

The growth of sweet clover for either 1 or 2 years under limited rainfall conditions may result in the development of a dry layer of depth sufficient to prevent the utilization of moisture at a lower level by subsequent alfalfa crops.

RELATION OF FALLOW TO RESTORATION OF SUBSOIL MOISTURE IN AN OLD ALFALFA FIELD AND SUBSEQUENT DEPLETION AFTER RESEEDING[1]

C. O. GRANDFIELD AND W. H. METZGER[2]

THE work of Kiesselbach, Russel, and Anderson[3] and of Duley[4] has shown that alfalfa is capable of depleting the subsoil moisture to the point where the crop is dependent on current rainfall for its growth. Furthermore, under the soil and climatic conditions existing at Manhattan, Kansas, and at Lincoln, Nebraska, it has been shown that after the subsoil moisture is depleted by alfalfa it is not regained under continuous cropping even with comparatively shallow-rooted crops. With these facts in mind an experiment was undertaken in 1930 on a well-drained upland soil at the Kansas Agricultural Experiment Station to obtain information regarding the effect of fallow on the restoration of subsoil moisture. This experiment was planned to determine the rate of restoration of moisture during fallow periods ranging from 1 to 5 years and the rate at which this moisture was again depleted by a new seeding of alfalfa.

EXPERIMENTAL METHODS

A field which had previously grown alfalfa for 4 years was plowed in December, 1929, and the first soil samples were taken in March, 1930. One fallow plat was sown each year for 5 years, hence the fallow periods varied from 1 to 5 years and the subsequent cropping periods from 1 to 5 years.

The soil, a dark brown silt loam, is underlaid at a depth of 15 to 18 inches by a moderately heavy subsoil. The slightly weathered parent materials are encountered at a depth of 30 to 36 inches and are probably of loessial origin. The soil is relatively friable throughout the zone of root penetration of most crops and the deep subsoil, as judged from the appearance of the samples, is friable to a depth of 20 feet. Sand strata and pockets occur between the 10- and 20-foot levels. The subsoil in the 20- to 25-foot area is rather heavy.

Clean fallow was practiced on all the plats prior to seeding, all growth being killed by cultivation and the surface ridged so that practically no runoff occurred during the 5 years.

[1]Cooperative investigations of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Kansas Agricultural Experiment Station, Manhattan, Kans. Contribution No 252, Department of Agronomy. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 6, 1935.

[2]Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Associate Professor of Soils, Kansas Agricultural Experiment Station, respectively. The authors wish to acknowledge the assistance of Dr. F. L. Duley who aided with the supervision of the experiment during the years 1930–33.

[3]KIESSELBACH, T. A., ANDERSON, A., and RUSSEL, J. C. Subsoil moisture and crop sequence in relation to alfalfa production. Jour. Amer. Soc. Agron., 26 : 422–442. 1934.

[4]DULEY, F. L. The effect of alfalfa on soil moisture. Jour. Amer. Soc. Agron., 21 : 224–231. 1929.

Duplicate soil samples for moisture determination were taken on each plat in 1-foot sections to a depth of 25 feet at the beginning of the fallow periods, when the plants were sown, and at intervals after reseeding. The samples were placed in tin sampling cans, covered promptly, and taken to the laboratory where the moisture percentage was determined in the usual way. Duplicate moisture equivalent determinations also were made on each sample of soil. The wilting coefficient was then calculated as proposed by Briggs and Shantz.[5] It is fully realized that the wilting coefficient for a given soil calculated from the formula, wilting coefficient $= \frac{\text{moisture equivalent}}{1.84}$, may or may not represent the point at which a plant could be expected permanently to wilt growing on that soil. The wilting coefficient is merely used here as a physical constant with which to compare the moisture content of the soil as affected, at various depths, by the different treatments.

The data on rainfall during the experimental period are shown in Table 1. The precipitation for the first 2 years was above normal and for the last 3 years and 9 months below normal with a total deficiency for the 5¾ years of 15.88 inches.

TABLE 1.—*Monthly and annual precipitation at Manhattan, Kansas, 1930 to 1935.*

Month	1930	1931	1932	1933	1934	1935	Normal
Jan.	0.85	0.12	1.03	0.12	0.62	0.16	0.77
Feb.	0.37	1.18	0.83	0.08	0.94	1.17	1.19
Mar.	0.52	1.64	0.40	1.82	0.31	0.21	1.50
Apr.	6.72	2.79	1.91	2.86	0.52	1.07	2.78
May	5.23	3.28	2.67	1.57	4.17	7.65	4.33
June	6.39	2.80	4.88	0.69	1.89	6.51	4.62
July	0.57	1.52	1.91	4.68	0.85	0.04	4.53
Aug.	4.99	10.52	4.11	4.07	0.80	8.63	3.74
Sept.	2.43	7.21	4.03	4.13	4.66	4.88	3.39
Oct.	2.86	2.04	0.60	1.03	0.63	—	2.29
Nov.	3.14	5.12	0.24	0.20	3.79	—	1.49
Dec.	0.11	0.53	1.32	0.69	0.20	—	0.86
Total	34.18	38.75	23.93	21.94	19.38	—	31.49
Departure from normal	+ 2.69	+ 7.26	— 7.56	— 9.55	—12.11	+3.48	—

EXPERIMENTAL RESULTS

The data from representative plats 4 and 6 are presented in Table 2 and are shown graphically in Figs. 1 and 2 as gains and losses from the original moisture content of each foot, thus demonstrating the effect of fallow and of alfalfa cropping. Plat 4 was fallowed 18 months followed by 4 years of alfalfa, while plat 6 was fallowed 30 months followed by 3 years of alfalfa. The samples from all plats showed that the soil moisture fluctuated more in the first 2 feet and the lowest 5 feet than in the intervening area. The changes in the upper strata

[5]BRIGGS, L. J., and SHANTZ, H. L. The wilting coefficient for different plants and its indirect determination. U. S. D. A. Bur. Plant Ind. Bul. 230: 1–83. 1924.

TABLE 2.—*Percentage gains and losses of soil moisture as affected by fallow and alfalfa cropping.*

Depth, feet	Plat 4						Plat 6				
	Dec. 15, 1930. 9 mos. fallow	Aug. 25, 1931,* 18 mos. fallow	Nov. 18, 1932, 14 mos. alfalfa	Dec. 8, 1933, 27 mos. alfalfa	Dec. 21, 1934, 39 mos. alfalfa	Aug. 15, 1935, 48 mos. alfalfa	Dec. 18, 1931, 21 mos. fallow	Aug. 12, 1932,* 30 mos. fallow	Dec. 22, 1933, 15 mos. alfalfa	Dec. 21, 1934, 28 mos. alfalfa	Aug. 15, 1935, 36 mos. alfalfa
1	—0.1	—1.6	—9.3	—9.5	+1.8	+3.3	+5.9	+3.9	—7.7	+4.2	+7.0
2	+0.8	+1.3	—7.2	—7.0	—3.0	+2.5	+3.4	+0.5	—6.6	—3.5	+1.9
3	+1.7	+1.4	—5.1	—6.3	—7.1	+1.7	+1.1	—0.7	—8.1	—8.9	—2.0
4	+5.7	+6.1	—2.0	—3.2	—2.8	+1.7	+6.1	+4.4	—4.4	—4.4	—4.2
5	+7.0	+8.3	—1.9	—2.5	—2.6	—1.3	+3.9	+5.5	—5.4	—5.4	—6.1
6	+6.3	+7.8	—0.7	—2.9	—2.0	—2.5	+6.8	+6.0	—4.1	—4.6	—5.3
7	+3.7	+7.9	0.0	—2.2	—2.8	—2.4	+6.8	+5.5	—3.3	—3.9	—4.5
8	+6.1	+8.0	+2.9	—1.1	—1.9	—1.2	+7.4	+6.6	—1.4	—2.4	—3.2
9	+0.7	+7.1	+4.8	—1.8	—2.1	—2.6	+9.0	+7.7	—0.8	—1.0	—1.6
10	—3.8	+5.0	+3.4	—2.2	—2.2	—1.6	+6.9	+6.9	—0.8	—2.3	—2.6
11	—1.2	+1.5	+4.0	—1.5	—2.1	—2.5	+5.2	+4.9	—0.4	—3.2	—3.2
12	—0.6	—0.7	+2.3	—1.1	—2.7	—3.0	+3.1	+2.0	—0.8	—4.0	—4.2
13	—1.0	+0.2	+3.0	0.0	—2.6	—3.1	+4.2	+2.4	—0.1	—3.7	—4.0
14	+1.2	+1.0	+3.0	+0.2	—2.1	—2.9	+2.7	+2.4	+0.6	—3.7	—3.5
15	+0.5	+1.1	+5.1	+0.4	—2.0	—2.1	+1.6	+4.0	+1.6	—2.1	—2.1
16	+3.0	—0.6	—0.1	—2.9	—3.8	—3.9	0.0	+3.0	+1.2	—4.1	—4.2
17	—0.3	+3.1	+2.2	—0.2	+0.9	—0.7	0.0	+3.1	+0.4	—5.5	—6.2
18	—2.5	+0.7	+4.1	—3.1	—1.5	—2.5	+0.7	—0.4	+0.1	—6.5	—6.4
19	—1.6	+0.2	+4.3	—0.5	—1.2	—3.5	+2.2	+2.2	+2.9	—4.8	—6.1
20	—1.9	+1.6	+2.2	—0.5	—0.2	—0.2	+4.2	+3.6	+2.0	—7.3	—9.5
21	—3.2	—2.4	+2.1	—7.5	+4.2	+0.6	+5.6	+8.1	+2.0	—8.0	—11.0
22	+0.7	—1.8	+2.8	—4.3	—0.3	—2.2	+5.8	+8.3	+2.4	—6.3	—8.0
23	+2.6	+0.1	+1.0	—1.5	+1.8	—2.5	+6.1	+11.3	+2.5	+3.7	—4.2
24	—1.5	—0.4	—0.5	—1.8	—2.6	—3.2	+2.3	+1.0	+0.3	+0.9	—2.7
25	—0.4	+0.1	+1.1	+1.6	—0.8	—2.6	+1.0	+2.4	+3.9	—1.8	+0.4

*Seeded to alfalfa.

were due to differential moisture penetration from rainfall just previous to sampling, while the differences in the lowest 5 feet were probably due to the variability of ground water seepage.

Fig. 1, constructed from the data of plat 4, shows the rate at which changes in the moisture supply take place under different treatments.

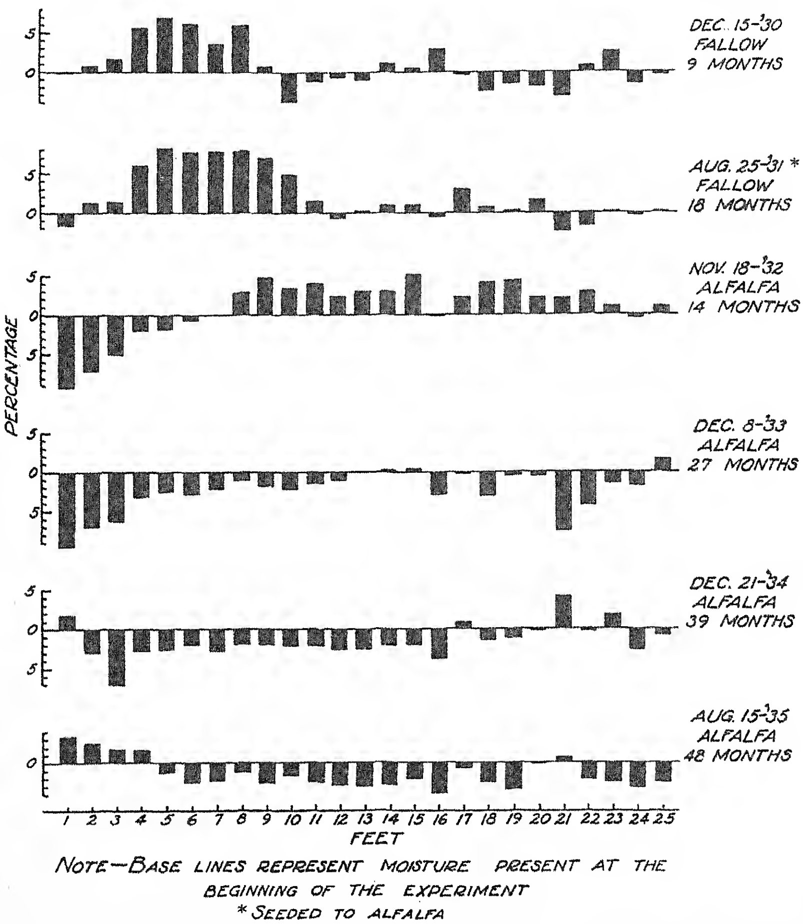

FIG. 1.—Gains and losses of soil moisture as affected by fallow and alfalfa cropping on plat 4.

As a result of 9 months of fallow the moisture increased to a depth of 8 feet as compared with the original moisture content with the exception of the first 2 or 3 feet which show the influence of a dry period at the time of sampling. After 18 months of fallow a further increase in moisture is noted to a depth of 11 feet, at which time alfalfa was sown, and 14 months later the moisture determinations showed that the new alfalfa had reduced the soil moisture below the original

moisture content to a depth of 8 feet. At the same time, however, there was an increase of moisture below 11 feet. It appears that part of the moisture accumulated from the 18 months of fallow had moved down while the new alfalfa roots evidently had not penetrated far enough to remove it. The moisture samples taken after 27 months

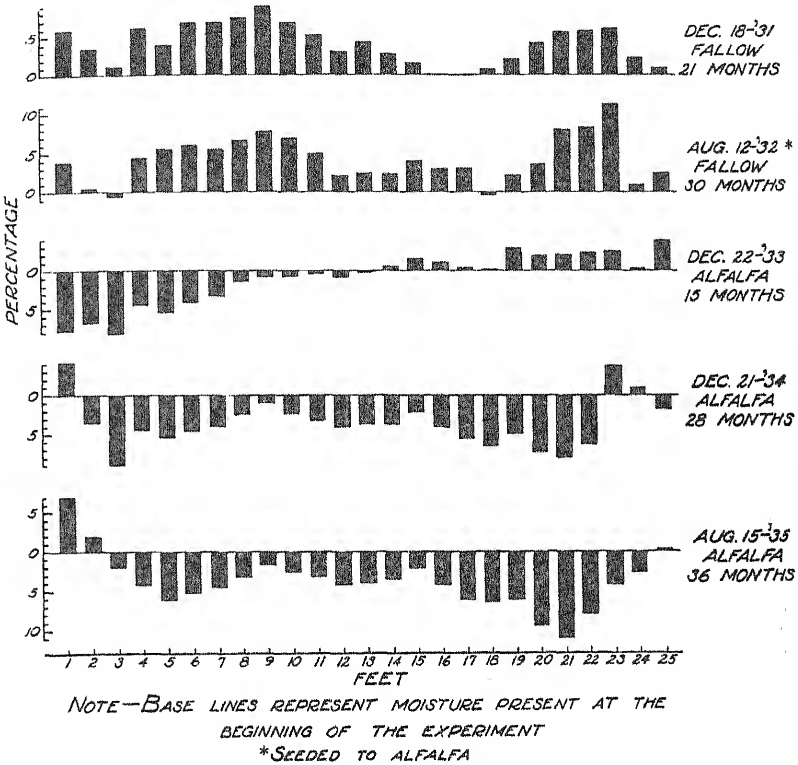

FIG. 2.—Gains and losses of soil moisture as affected by fallow and alfalfa cropping on plat 6.

of alfalfa cropping showed that the accumulated moisture was reduced practically to, or below, the original content at all depths. All subsequent samples on this plat showed similar results.

The data of plat 4 indicate that 18 months of fallow were not sufficient to produce an increase in the moisture of the subsoil below 11 feet. Fig. 2 shows graphically the data from plat 6 after periods of 21 and 30 months of fallow. These data indicate that a period between 21 and 30 months duration was necessary to obtain an increase in the moisture content at all depths. They also indicate that 15 months of alfalfa cropping removed the stored moisture to a depth of 12 feet and 28 months of cropping to a depth of 25 feet.

The physical properties of a soil influence its water-holding capacity and the thoroughness with which plants are able to remove the water.

Therefore, the extent of removal of available moisture was measured and the moisture content for each foot was compared to its wilting coefficient. It was found that the coefficient did not vary greatly from plat to plat for similar depths except in the lowest 5 feet, which again indicates the irregularity of the soil at this depth.

The data show that the soil had been depleted of its moisture by the previous alfalfa cropping to a point near or below the wilting coefficient to a depth of 20 feet. From the twentieth foot to the twenty-fifth foot, inclusive, there was a layer of soil that had a high moisture content indicating seepage from an underground source. The nineteenth foot was sandy and had the lowest wilting coefficient of any depth.

Table 3 shows the variations of the actual moisture contents as compared with the wilting coefficient for the various soil sections from plats 4 and 6. These data show the effect of the fallow and alfalfa cropping periods on the storage and removal of theoretically available moisture. Figs. 3 and 4 present the data graphically. The data for the first sampling date indicate that at the beginning of the experiment the amounts of moisture in all sections sampled with one exception were above the wilting coefficients. After 9 months of fallow (Fig. 3) the moisture available to the plants had increased to a depth of 9 feet, and after 18 months it had increased to a depth of 11 feet. Fourteen months of alfalfa cropping again removed this available moisture to a depth of 7 feet and in 27 months it had removed all available moisture to the wet layers found in all plats at, or below, 20 feet. In plat 6, as shown in Fig. 4, the moisture at the beginning of the experiment was not so nearly exhausted as in plat 4. As a result of 21 months of fallow a substantial increase in available moisture was obtained to a depth of 15 feet. After 30 months of fallow available moisture had increased in all depths. Fifteen months of alfalfa cropping took out all the accumulated moisture to a depth of 13 feet and 27 months removed the moisture completely to a depth of 21 feet, or to the more or less constantly wet area.

It is evident from the data given in Table 3 and presented graphically in Figs. 3 and 4 that as compared with the wilting coefficient the soil moisture increased as the fallow period increased, from 21 to 30 months being required for this increase to reach the 25-foot depth. The results also show the thoroughness with which the stored moisture was removed by a subsequent cropping of alfalfa, all the accumulated moisture being removed in 15 to 27 months of alfalfa cropping. This would indicate that after such removal the plants must depend largely on seasonal rainfall for their moisture supply except where roots had penetrated deep enough to reach moist soil at lower depths.

In the Nebraska work, cited previously, a 5-year period of fallow failed to restore the moisture removed below the 14-foot level by previous alfalfa cropping. The difference in the rate of restoration of subsoil moisture under fallow in the Nebraska experiments and the Kansas experiments emphasizes the importance of variability in soils and climatic conditions in determining the time required to restore the deep subsoil moisture.

TABLE 3.—*Percentage variation from the wilting coefficient of soil moisture as affected by fallow and alfalfa cropping.*

Depth in feet	Plat 4, treatment and date of sampling								Plat 6, treatment and date of sampling						
	Wilting coefficient	Initial, Mar. 15, 1930	9 mos. fallow, Dec. 15, 1930	18 mos. fallow, Aug. 25, 1931*	Alfalfa 14 mos. Nov. 18, 1932	Alfalfa 27 mos., Dec. 8, 1933	Alfalfa 39 mos., Dec. 21, 1934	Alfalfa 48 mos., Aug. 15, 1935	Wilting coefficient	Initial, Mar. 15, 1930	21 mos. fallow, Dec. 18, 1931	29 mos. fallow, Aug. 12, 1932*	Alfalfa 15 mos., Dec. 22, 1933	Alfalfa 27 mos., Dec. 21, 1934	Alfalfa 36 mos., Aug. 15, 1935
1	14.0	+10.3	+10.2	+ 8.7	+ 1.0	+0.6	+12.1	+13.6	13.6	+ 7.5	+13.4	+11.4	− 0.2	+11.7	+14.5
2	16.4	+ 9.9	+10.7	+11.2	+ 2.7	+2.9	+ 6.9	+12.4	17.5	+ 8.4	+11.8	+ 8.9	+ 0.8	+ 4.9	+10.3
3	16.2	+ 6.8	+ 8.5	+ 8.2	+ 1.7	+0.5	− 0.3	+ 8.5	16.5	+ 8.9	+10.0	+ 8.2	+ 0.8	0.0	+ 6.9
4	15.9	+ 3.1	+ 8.8	+ 9.2	+ 1.1	−0.1	+ 0.3	+ 4.8	15.5	+ 4.7	+10.8	+ 9.1	+ 0.3	+ 0.3	+ 0.5
5	15.4	+ 2.2	+ 9.2	+10.5	+ 0.3	−0.3	− 0.4	+ 0.9	15.0	+ 5.4	+10.3	+ 9.9	0.0	0.0	− 0.7
6	14.2	+ 2.5	+ 8.8	+10.3	+ 1.8	−0.4	+ 0.5	+ 0.1	14.2	+ 4.6	+11.4	+10.6	+ 0.5	0.0	− 0.7
7	14.4	+ 2.2	+ 5.9	+10.1	+ 2.2	0.0	− 0.6	− 0.2	13.9	+ 3.9	+10.7	+ 9.4	+ 0.6	0.0	− 0.6
8	15.0	+ 1.3	+ 7.4	+ 9.3	+ 4.2	+0.2	− 0.6	+ 0.1	13.8	+ 3.1	+10.5	+ 9.7	+ 1.7	+ 0.7	− 0.1
9	14.5	+ 1.3	+ 2.0	+ 8.4	+ 6.1	−0.5	− 0.8	− 1.3	14.3	+ 1.2	+10.2	+ 8.9	+ 0.4	+ 0.2	− 0.4
10	14.0	+ 1.4	− 0.4	+ 6.4	+ 6.4	−0.8	− 0.8	− 0.2	14.5	+ 1.3	+ 8.2	+ 8.2	+ 0.5	− 1.0	− 1.3
11	13.5	+ 0.7	− 0.5	+ 1.7	+ 4.7	−1.2	− 1.4	− 2.8	14.4	+ 1.4	+ 6.6	+ 6.3	+ 1.0	− 1.8	− 1.8
12	12.8	+ 1.3	+ 0.7	+ 0.6	+ 3.6	−0.2	− 1.4	− 1.7	13.7	+ 2.3	+ 5.4	+ 5.1	+ 1.5	− 1.7	− 1.9
13	12.3	+ 1.3	+ 0.3	+ 1.5	+ 4.3	−0.3	− 1.3	− 1.8	13.0	+ 2.2	+ 6.4	+ 4.6	+ 2.1	− 1.5	− 1.8
14	12.0	+ 0.7	+ 1.6	+ 1.7	+ 3.7	−0.9	− 1.4	− 2.2	13.2	+ 1.7	+ 4.4	+ 4.1	+ 2.3	− 2.0	− 1.8
15	11.8	+ 0.4	+ 0.9	+ 1.5	+ 5.5	−0.8	− 1.6	− 1.7	13.2	− 0.1	+ 1.5	+ 3.9	+ 1.5	− 3.2	− 2.2
16	12.5	+ 2.6	− 0.4	+ 2.0	+ 2.5	−0.3	− 1.2	− 1.3	12.6	+ 0.8	+ 0.8	+ 3.8	+ 6.0	− 3.3	− 3.4
17	13.4	− 0.8	− 0.5	+ 2.3	+ 1.4	−1.0	− 0.1	− 1.5	12.0	+ 2.8	+ 2.8	+ 5.9	+ 2.4	− 2.7	− 3.4
18	12.6	+ 1.1	+ 1.4	+ 1.8	* 5.2	−2.0	− 0.4	− 1.4	11.7	+ 3.6	+ 4.3	+ 3.2	+ 3.7	− 2.9	− 3.8
19	9.0	+ 2.9	+ 1.3	+ 3.1	+ 7.2	−2.4	+ 1.7	− 0.6	10.0	+ 3.6	+ 5.8	+ 5.8	+ 6.5	− 1.2	− 2.5
20	13.3	+ 1.6	− 0.3	+ 3.2	+ 3.8	−1.1	+ 1.4	+ 1.4	8.6	+ 7.3	+11.5	+10.9	+ 9.3	0.0	− 2.2
21	17.8	+ 8.4	+ 5.2	+ 6.1	+10.5	+0.9	+12.6	+ 9.0	8.2	+10.1	+15.7	+18.2	+12.1	+ 2.1	− 0.9
22	15.1	+11.9	+12.6	+10.1	+14.7	+4.6	+11.6	+ 9.7	9.8	+ 8.1	+13.9	+16.4	+10.5	+ 1.8	+ 0.1
23	12.7	+ 9.1	+11.7	+ 9.2	+10.1	+7.6	+10.9	+ 6.6	9.2	+ 6.5	+12.6	+17.8	+ 9.0	+10.2	+ 2.3
24	9.3	+ 8.0	+ 6.5	+ 7.6	+ 7.5	+6.2	+ 5.4	+ 4.8	9.9	+ 6.5	+ 8.8	+ 7.5	+ 6.8	+ 7.4	+ 3.8
25	9.5	+ 8.2	+ 7.8	+ 8.3	+ 9.3	+9.8	+ 7.4	+ 5.6	11.0	+ 7.5	+ 8.5	+ 9.9	+11.4	+ 5.7	+ 7.9

*Seeded to alfalfa.

SUMMARY

In experiments conducted at Manhattan, Kansas, it was found that alfalfa cropping had depleted the soil of available moisture to a depth of nearly 25 feet. Clean fallow restored the available subsoil moisture to a depth of 25 feet in approximately 2 years and a subsequent seeding of alfalfa again depleted this moisture in about the same length of time. The conclusion is drawn, therefore, that 2

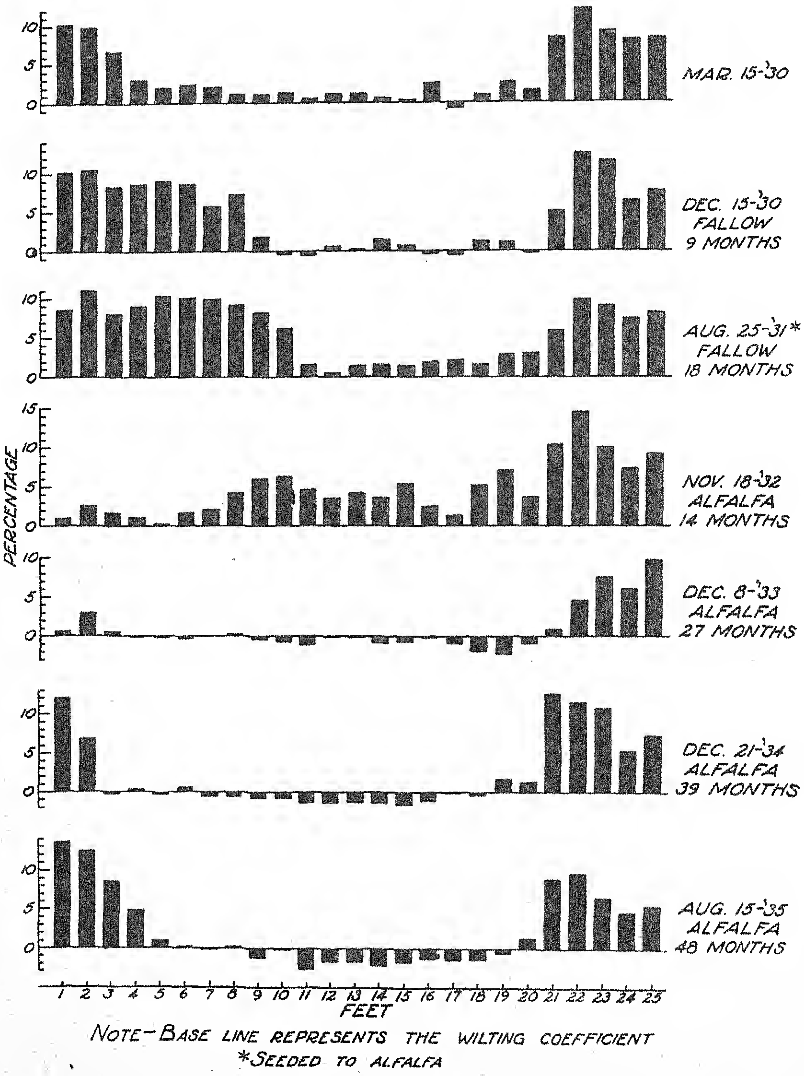

FIG. 3.—Variation of soil moisture from the wilting coefficient as affected by fallow and alfalfa cropping on plat 4.

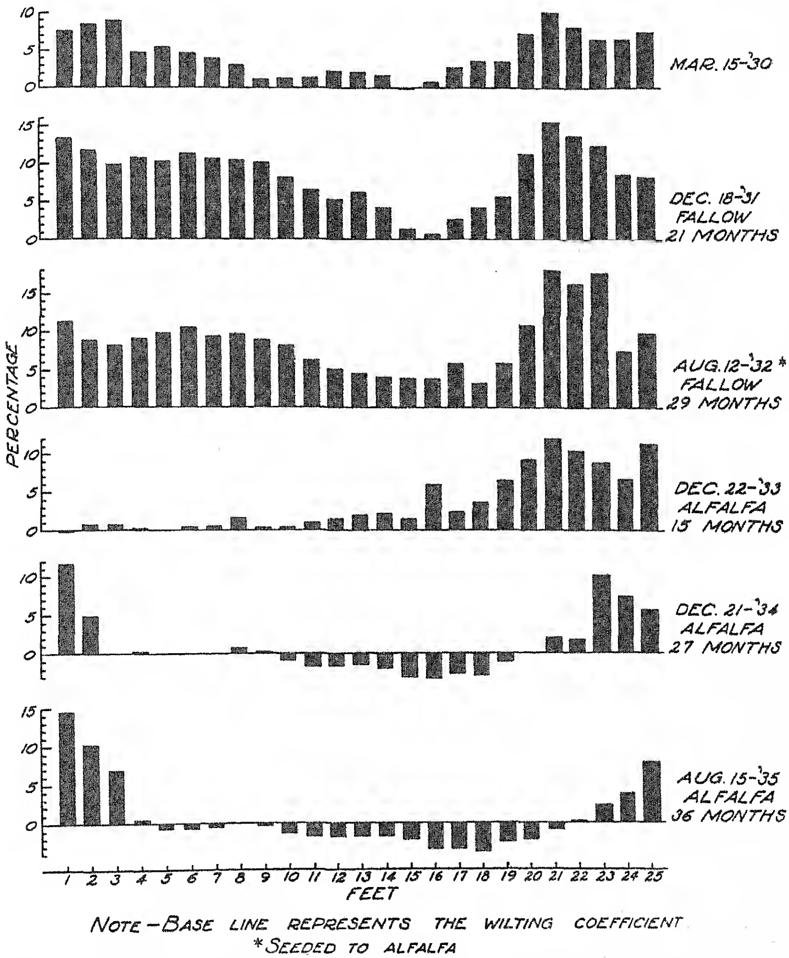

FIG. 4.—Variation of soil moisture from the wilting coefficient as affected by fallow and alfalfa cropping on plat 6.

years of fallow were necessary to restore subsoil moisture on old alfalfa ground to a point where the roots of a newly seeded crop could penetrate through moist soil to a depth of 25 feet or more. Two years after seeding alfalfa the subsoil was depleted of moisture to a point near the wilting coefficient, making it necessary for the crop to depend on current rainfall, unless the root penetration had been deep enough to reach moisture at lower depths.

THE RELATION OF SOIL MOISTURE TO PEAR TREE WILTING IN A HEAVY CLAY SOIL[1]

R. A. WORK AND M. R. LEWIS[2]

THE conclusions reached by various workers as to the availability to plants of soil moisture above the permanent wilting percentage as defined by Hendrickson and Veihmeyer (9)[3] differ rather definitely. In this report further evidence in support of the conclusion that all moisture above that point is not equally available is presented and a hypothesis supporting this conclusion, heretofore presented by Vasquez (16), Magness (13), and Lewis, Work, and Aldrich (12), is further amplified.

Bartholomew (5) says, "The leaves themselves may not wilt until the wilting coefficient of the soil has been reached, but the fruits may begin to suffer long before." He concluded that the root system of a lemon tree, even with highly available soil moisture, is unable to afford the fruit enough water to prevent suffering of the fruit during periods of high transpiration opportunity.

Furr and Degmen (7) report that, "The data . . . indicate that the relative amount of available soil moisture had a measurable, though slight, influence on fruit growth and a marked influence on stomatal behavior while the soil moisture is several per cent above the wilting percentage."

As a result of studies of the irrigation requirements of pear trees, Aldrich and Work (1) and Lewis, Work, and Aldrich (12) found that differential amounts of soil moisture within the available range exert a profound influence upon pear fruit size and consequent yield. Aldrich and Work (2) have also shown that soil moisture variations within the available range influence the amount of fruit bud formation.

With pear trees in heavy clay soil the senior author found (20) that during periods of relatively uniform weather conditions moisture is lost from all soil depths at a decreasing rate as the moisture content decreases, beginning, ordinarily, when from 50 to 60% of the available soil moisture is still present.

The conclusions of this group of workers may be summarized by the statement that fruit trees may suffer for water, as evidenced by slowing up in the growth rate of fruit and by decrease in the rate of extraction of soil moisture, long before the moisture content of the soil of any material portion of the root zone is reduced to the permanent wilting percentage.

On the other hand, other workers conclude that soil moisture above the permanent wilting percentage is readily available to plants and that trees do not

[1]This paper is a report of investigations initially conducted under a cooperative agreement between the Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, and the Soils Department, Oregon Agricultural Experiment Station, and later with the additional cooperation of the Bureau of Plant Industry, U. S. Dept. of Agriculture. Published as Technical Paper No. 241 with the approval of the Director as a contribution of the Medford Branch of the Oregon Agricultural Experiment Station, Medford, Ore. Received for publication December 9, 1935.

[2]Associate Irrigation Engineer, Division of Irrigation, Bureau of Agricultural Engineering, U. S. Dept. of Agriculture, and Irrigation Engineer, Soils Department, Oregon Agricultural Experiment Station and Division of Irrigation, Bureau of Agricultural Engineering, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 134.

suffer until the soil of some part of the root zone is reduced to approximately the permanent wilting percentage.

Hendrickson and Veihmeyer (9) and Veihmeyer and Hendrickson (18) define "permanent wilting percentage" as the soil moisture condition at which plants wilt and do not recover unless water is applied to the soil. They hold that the permanent wilting percentage is a narrow range of soil moisture content within which wilting takes place. They define "readily available moisture" as the entire range of soil moisture between field capacity and approximately the permanent wilting percentage.

Hendrickson and Veihmeyer (10) say, "The substantially uniform extraction rate between the field capacity and the permanent wilting percentage indicates that prune trees can obtain water with equal facility from the field capacity to about the permanent wilting percentage."

Taylor, Blaney, and McLaughlin (15) state that, "it appears that soil moisture is readily available to well established plants down to the wilting coefficient as defined by Briggs and Shantz." They define the "ultimate wilting point" as the condition of the plant when *all* the leaves are wilted. Their "ultimate wilting point" is slightly lower than the criterion of wilting we have used at Medford, since usually we did not wait for the apical leaves of the plants to wilt.

Veihmeyer and Hendrickson, and Taylor, Blaney, and McLaughlin as well, recognize a visible range of plant suffering due to a water deficit, but neither group appear to have observed that period when, although the water content of the soil, as nearly as it can be measured by the usual methods of sampling, is well above the permanent wilting percentage, such tree responses as time of stomatal opening and rate of growth of fruit and twigs are reduced by reason of a water deficit in the plants, which latter in turn may be traced to a deficiency in soil moisture.

Gradually an explanation of these apparently contradictory views has been formulated. Vasquez (16) points out that on days of high transpiration opportunity the plants may suffer even if there is still available water in the soil and offers the hypothesis that at such times only the zone of soil immediately surrounding the roots is dry and the rest still holds available water. Magness (13) expresses very clearly the opinion which Aldrich and Work (1), Lewis, Work, and Aldrich (12), and Work and Aldrich (21) had come to independently that the slow capillary movement and sparse root population in heavy soils as compared to lighter soils so slowed up the absorbtion of water by the roots that trees might suffer before the moisture content of the soil of any zone large enough to be sampled by customary methods was reduced even approximately to the wilting point.

Furr and Magness (8) found a marked difference in the daily period of stomatal opening and the rate of growth of apples between irrigated and non-irrigated plats when "on the basis of the average condition of soil moisture the dry plat was appreciably above the wilting percentage", but go on to say, " it is highly probable, however, that localized soil areas containing a fairly high root population were reduced to the wilting percentage at this time."

It appears from the above quotation that in 1930 Furr and Magness were still thinking in terms of comparatively large bodies of soil.

In many of the studies heretofore reported the evidence of suffering on the part of the trees and the intensity of soil sampling have been such as to leave some doubt as to the proof of suffering while all parts of the root zone held water above the wilting point. At Medford, Ore., unmistakable evidence of extreme suffering of pear trees has been

observed when intensive soil sampling showed that all parts of the root zone held available water. The term "sample average" is used herein to designate the moisture content of any one particular soil sample 7/8 inch in diameter taken from 1 foot depth of soil at any level. Those observations and a suggested explanation are reported herewith.

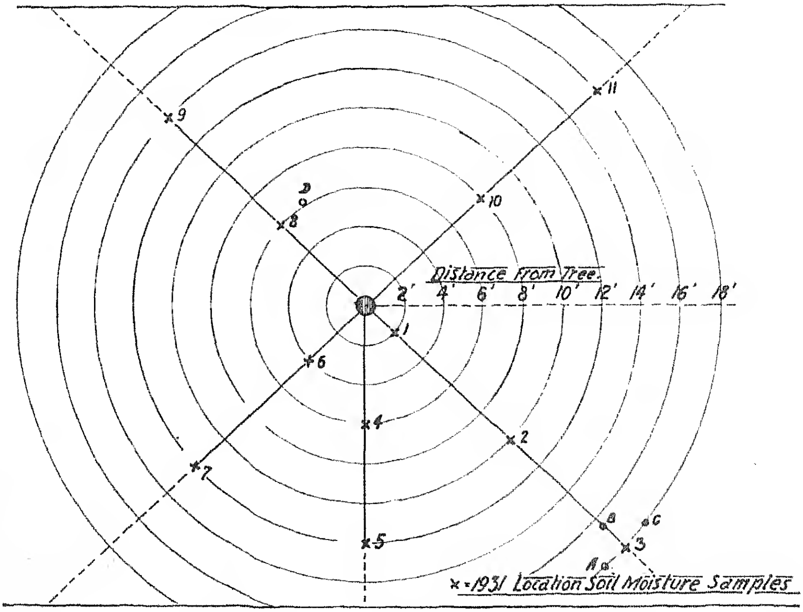

FIG. 1.—Sampling locations, tree E4, 1931.

TREE AND SOIL USED

In 1931, tree E4 in the Klamath orchard (11) near Medford, an Anjou pear tree on French root stock, was 26 years old, with a trunk circumference of 68.7 cm and an average limb spread of about 12.4 feet. The soil is Meyer clay adobe, a nearly black clay of pronounced adobe structure, bedded on shale at a depth of 4 feet.

SOIL SAMPLING METHODS

The 11 sampling locations, all within the root zone of tree E4, are shown in relation to the trunk of that tree in Fig. 1. Samples were taken with the soil tube from the underside of the mulch to bedrock and the moisture content of each foot depth of each hole was determined at each date of sampling. Moisture contents are reported on the dry weight basis. Sampling started May 12, 1931, and terminated on December 8 of the same year. Between May 12 and September 15 the average interval between sampling dates was 10 days.

PERMANENT WILTING PERCENTAGE DETERMINATIONS

Determinations of the permanent wilting percentage were made in 1932 for each foot depth at each of four sampling locations, *viz.*, Nos. 3, 7, 8, and 11. Samples for wilting percentage determinations were taken at a 1-foot offset from the regular sampling locations, and the soil was prepared and determinations were made by methods described by Work and Lewis (19). A summary of these determinations, each of which is an average of eight individual tests, is shown in Table 1.

TABLE 1.—*Wilting percentage for each foot depth at four locations in root zone of tree E4, Klamath Orchard, 1932.*

Sampling location*	0–1%	1–2%	2–3%	3–4%
3†	18.2	19.3	17.7	—
7‡	13.1	15.5	14.5	15.6
8‡	12.4	15.0	14.1	13.3
11‡	12.0	16.1	15.7	13.5

*See Fig. 1.

†Determinations made in March, April, and May, 1932, under greenhouse conditions. Humidifier used.

‡Determinations made in August, September, and October, 1932, under outside growing conditions. Humidifier used.

It will be noted on examination of Table 1 that there is a wide difference between the permanent wilting percentage for hole 3 and for holes 7, 8, and 11 at all depths. The reason for this is somewhat speculative. Conditions under which the plants were grown might account for some of the difference. Plants in soil from location 3 were grown in a greenhouse during early spring and were not as vigorous as the plants grown outside in the late summer in soil from locations 7, 8, and 11. The average top green weight of the 19 plants growing in soil from location 3 was 1.8 grams at the time of wilting, but the average top green weight for 71 plants growing in soil from locations 7, 8, and 11, was 2.3 grams. These latter more vigorous plants probably made more extensive root growth and therefore would be likely more completely to use all the available moisture in the soil of the container. Visible root population of even the most thrifty sunflower plants, is relatively sparse in these heavy clay soils. On the other hand, some variation of soil texture or structure at location 3 may have caused a higher permanent wilting percentage value there.

In order to determine if this were the case, additional wilting percentage determinations were made in 1935 for each foot depth to 4 feet at each of four locations. Holes A, B, and C were 1½ feet northeast, 1½ feet southeast, and 1½ feet southwest, respectively, of sampling location 3. Hole D was 1½ feet southwest of sampling location 8, as shown in Fig. 1. Determinations of the "permanent wilting percentage" were made by V. C. Hill at Oregon State College. Table 2 is a summary of these determinations each of which is an average of eight individual tests. Determinations were made in March and April 1935 under greenhouse conditions.

The average permanent wilting percentage representing holes A, B, and C, all within a radius of 1½ feet of hole 3, is lower at every depth

TABLE 2.—*Wilting percentage for each foot depth at four locations in root zone of tree E4, Klamath Orchard, 1935.*

Sampling location*	0–1%	1–2%	2–3%	3–4%
A	14.5	16.8	16.7	17.0
B	14.8	16.5	17.5	17.5
C	14.0	16.6	16.8	17.3
D	14.1	15.8	16.5	16.9
Average of A, B, C	14.4	16.6	17.0	17.3

*See Fig. 1 for location.

than that of hole 3. This would indicate that the less vigorous plants grown on soil from location 3 in 1932 did not reduce the soil moisture in those samples to as great a degree as more vigorous plants grown in the late spring of 1935 on soil from adjacent sample locations.

The average permanent wilting percentage for locations A, B, and C determined in 1935 is substituted for the values determined in 1932 for location 3. In the subsequent discussion the average permanent wilting percentage for tree E4 is assumed to be the average of values for holes 7, 8, and 11 and the A, B, C average. Those values are: 0–1, 13.0%; 1–2, 15.8%; 2–3, 15.3%; and, 3–4, 14.9%.

Examination of the data shows the wilting percentage as determined in 1935 for all depths at location D (1½ feet distant from location 8) to range from 0.8% to 3.6% higher than those of samples from location 8 determined in the fall of 1932. No ready explanation for this difference offers. The two sets of determinations were made under differing environmental conditions by separate workers. Some variation of soil texture at location 8 may have caused higher values at every depth there. However, since the values found at location 3 in 1932 are out of line both with the values found later in 1932 and in 1935 and because environmental conditions for determinations made on samples from that location differed from those prevailing for determinations made at locations 7, 8, and 11, we feel justified in discarding the values obtained in 1932 for hole 3. Whether determinations of the permanent wilting percentage made at location D in 1935 or those made at location 8 in 1932 represent the true values for that sector of the root zone of tree E4 is not particularly important, as will be shown in subsequent discussion.

SOIL MOISTURE DATA

The soil moisture content of each foot depth in each sampling location is shown for several dates in Table 3 and the average for each foot is plotted on Fig. 2 for the period July 18 to November 2, 1931.

RESULTS AND DISCUSSIONS

On August 17, 1931, no trees in plat E of the Klamath Orchard appeared wilted. On August 19, 1931, it was noted that trees E2, E3, and E4 were badly wilted. No spray burn or red spider damage could be observed on these trees. On August 23 it was noted that other nearby trees were showing wilting. On August 24 pressure tests were made on 22 fruits from plat E. Eleven fruits were taken at random

TABLE 3.—*Soil moisture contents on a dry weight basis, tree E4, late summer, 1931.*

Location No.	Aug. 4, %	Aug. 19, %	Aug. 27, %	Sept. 15, %	Oct. 14, %
		0 to 1 Foot			
1	16.9	16.7	14.5	15.8	14.6
2	22.1	22.0	21.0	21.2	16.5
3	25.5	22.5	16.8	20.2	17.1
4	20.2	15.2	16.1	17.2	15.1
5	22.3	18.3	16.8	15.7	16.2
6	15.8	13.6	16.3	14.5	15.1
7	20.2	16.4	17.4	17.7	16.8
8	17.3	20.2	13.8	15.7	15.2
9	21.2	17.4	16.5	18.4	15.7
10	20.8	19.1	14.8	14.8	12.5
11	23.6	18.6	17.7	16.5	15.4
Average	20.5	18.2	16.5	17.1	15.5
		1 to 2 Feet			
1	18.5	18.4	17.8	17.5	17.5
2	22.8	22.7	22.6	19.8	22.1
3	22.3	18.9	18.7	21.2	17.3
4	19.9	17.2	18.7	18.0	18.6
5	23.3	22.0	18.0	17.1	17.5
6	18.0	16.7	16.7	16.3	17.3
7	22.7	17.9	18.2	19.0	19.0
8	19.6	23.1	20.6	17.9	19.2
9	21.6	20.2	20.2	22.9	22.3
10	23.8	21.1	16.9	16.6	15.9
11	24.2	22.8	19.1	18.8	20.1
Average	21.5	20.1	18.9	18.6	18.8
		2 to 3 Feet			
1	18.9	19.6	17.8	16.9	18.0
2	21.4	20.4	19.5	16.9	20.8
3	20.1	19.3	18.4	15.5	18.0
4	19.1	17.9	18.2	18.5	18.8
5	20.5	20.2	23.6	17.0	16.5
6	21.3	17.6	16.6	16.7	17.0
7	22.9	17.6	18.5	18.3	18.4
8	23.6	18.0	18.1	15.8	17.9
9	25.0	23.0	22.9	17.8	22.0
10	26.4	23.0	19.4	20.4	18.4
11	23.6	23.4	21.1	18.8	18.9
Average	22.1	20.0	19.5	17.5	18.6
		3 to 4 Feet			
1	—	15.9	17.1	17.3	17.4
2	—	—	15.6	—	—
3	19.0	—	—	14.8	—
4	18.5	16.7	16.0	16.4	17.6
5	15.5	17.8	14.4	16.0	12.4
6	16.6	14.1	16.1	14.5	14.8
7	17.4	17.7	15.5	15.2	15.8
8	21.4	18.4	16.0	14.0	19.1
9	22.4	22.2	21.1	18.0	19.1
10	25.6	18.8	16.3	16.0	17.5
11	19.4	21.5	17.7	17.8	18.9
Average	19.5	18.1	16.6	16.0	16.9

from unwilted trees, seven from trees E2 and E3 which were wilted (at 7 a. m.), and four from tree E4 which was badly wilted and about one-third defoliated. Flesh firmness by the Oregon type of tester for the three lots was as follows: 23.7 pounds, 25.1 pounds, and 25.9 pounds, respectively. The firmness of the fruit from the wilted trees was higher than that from the unwilted trees.

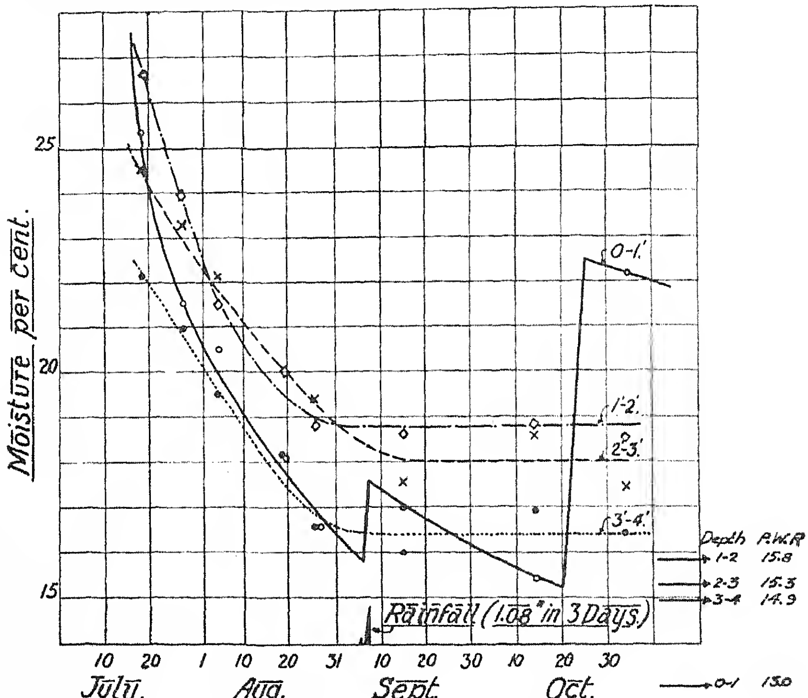

FIG. 2.—Soil moisture content, tree E4, 1931.

It appears that on the wilted trees a water deficit in the leaves resulting from transpiration withdrew water from the fruit, and by toughening of the cortical cells increased the pressure required for penetration of the pressure tester plunger. In the case of citrus Bartholomew (5) points out that detached lemons will not decrease in volume as much as fruit on detached limbs. Chandler (6), working with peaches, grapes, cherries, and small fruits, found that water would move from the fruit to the leaves, causing shrivelling of fruit if the water supply to the leaves became limited. These references are cited and data on pressure tests given as further indication of the acute condition of wilting reached by the tree on August 24.

This tree first showed visible wilting of the leaves on August 19, yet on that date the average soil moisture content of each foot level was several per cent above the average permanent wilting percentage for that level. Of the 42 determinations of soil moisture made that day only 2, namely, hole 6, depth 0 to 1 foot, and hole 6, depth 3 to

4 feet, showed moisture contents as low as the average permanent wilting percentages for their respective depths. The average soil moisture contents of the first, second, third, and fourth feet were 5.2, 4.3, 4.7, and 3.2 %, respectively, above the average permanent wilting percentages for the corresponding depths. On this date the tree was still extracting moisture from the soil at nearly a normal rate as will be seen from an inspection of Fig. 2.

However, except for the first foot, extraction of moisture had materially slowed down by August 27, yet the average moisture content of none of the upper 4 feet, containing almost all of the roots (4), had reached the permanent wilting percentage. Examination of Table 3 shows that on that date of the 43 soil moisture samples from 11 locations and four depths in the root zone of tree E4, in only one, namely, hole 8, depth 0 to 1 foot, had the soil moisture reached the permanent wilting percentage. The average moisture contents of the first, second, third, and fourth feet were 3.5, 3.1, 4.2, and 1.7%, respectively, greater than the permanent wilting percentages of the respective depths.

Rate of moisture extraction decreased rapidly at all levels, except the first foot, after wilting occurred, and by September 15 had ceased. Based on the rate of soil moisture extraction rather than on observed tree response, all levels except the first foot had reached the lower limit of availability by the later date. Withdrawal from the second foot ceased at about 19%, from the third foot at about 18% and from the fourth foot at about 16%, these percentages being 3.2, 2.7, and 1.1 higher than the permanent wilting percentages for the corresponding depths.

Taylor, Blaney, and McLaughlin (15) refer to such curved lines of extraction by stating that "any flattening of curves showing average rate of extraction of soil moisture must be taken as evidence that some portion of the root zone has approached the wilting range." The evidence herewith presented does not necessarily contradict that statement because we have so far been unable to show the moisture content of soil directly in contact with absorbing root surface. However, so far as our present technique of soil sampling for moisture content can determine, we have found the rate of loss of soil moisture to decline progressively, beginning long before the average soil moisture content of any portion of the root zone large enough to sample has approached the permanent wilting percentage.

Unpublished studies by the authors of the rate of infiltration and penetration of irrigation water on this soil show that the rate of downward movement is very slow. This fact, together with the general character of the soil, make it reasonable to assume that lateral movement of moisture by capillary action is also very slow. McLaughlin (14), Veihmeyer and Hendrickson (17), and others have shown that the rate of movement of moisture by capillary action from moist to dry soil is too slow through any large distance to supply the needs of plants.

Observations on visible small roots in several pear orchards at Medford (4) have shown that in these heavy clay soils the roots do not occupy the entire soil mass.

These facts and the results of the work at Medford seem to lead to the following explanation of the different conclusions cited at the beginning of this paper.

The roots first extract moisture from the soil in immediate contact with the roots. The soil moisture at contact points may be depleted to the permanent wilting percentage as determined by growing potted sunflower plants. If the rate of movement of water through the soil to the dried out soil is slower than the rate of extraction by the roots, we should have the phenomenon of an envelope of soil around the extracting root hairs in which the moisture content was at or near the permanent wilting percentage, while outside the envelope, at a few millimeters or some other distance from the root, the soil moisture might be well above the permanent wilting percentage and moving slowly toward the root.

In view of the fact that roots do not seem to occupy all parts of the soil mass (4) and in view of the slow rate of water movement through the soil, it seems likely that a condition of scattered volumes of soil whose soil moisture content may be at or closely approaching the permanent wilting percentage, interspersed through a body of soil whose moisture content is well above the wilting percentage, prevails when trees suffer while soil samples show available moisture in all parts of the root zone. Fig. 3 diagrammatically illustrates this idea. The cross section around the roots has been greatly enlarged and is not in proportion to the rest of the sketch, since the areas of soil around each root, here considered, are so small that it is impossible to check them by ordinary soil sampling means. In taking soil samples in the field the core of each whole foot in depth usually is taken, which would include soil both in and out of the dry soil envelopes. Therefore, in such cases, each "sample average" would always be greater than the wilting percentage as determined by growing potted sunflower plants, except when the concentration of tree roots per unit of rooting space equalled that of the roots of the potted sunflower plants, or when moisture moves so freely through the soil as rapidly to equalize zones of uneven moisture content. Conceivably a very occasional hole parallelling a series of extracting roots might show at all depths the permanent wilting percentage. This would not occur very often under conditions of sparse root population. Where as many as 11 locations per tree are sampled, the possibility of all locations reflecting the permanent wilting percentage at the time the tree first shows unmistakable signs of lack of readily available water would be extremely small.

This hypothesis is supported by data secured in 1934 by Aldrich and Work (3) who found that removal of 20% of the roots of pear trees in clay soil resulted in water deficit to the trees during warm summer weather.

SUMMARY

One group of workers believes that trees may suffer for lack of water while the moisture content of all material portions of the roots zone is still well above the permanent wilting percentage.

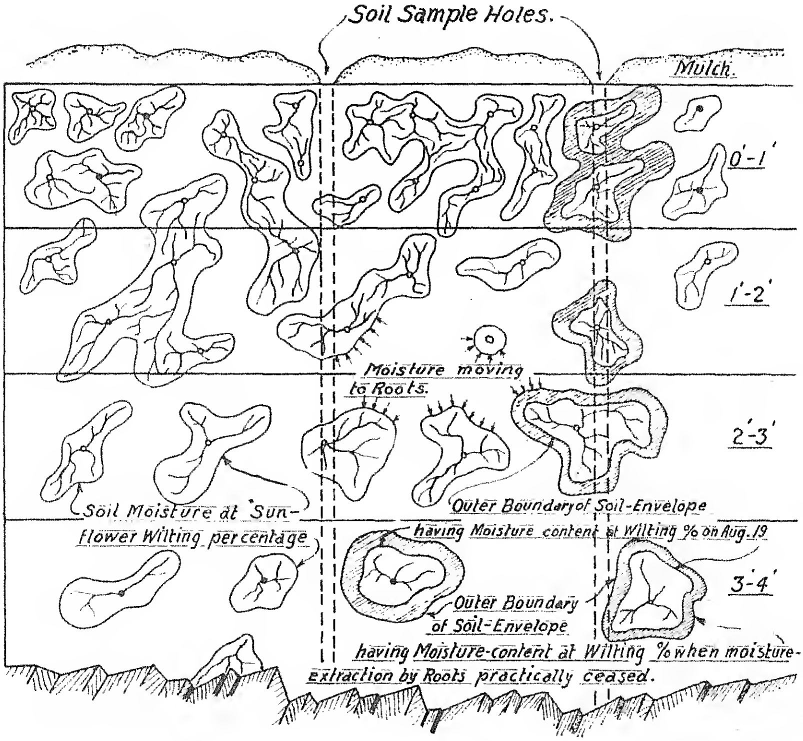

FIG. 3.—Hypothesis of soil moisture conditions in root zone of Klamath tree E4 from incipient to permanent wilting in 1931. (The cross section around the roots has been greatly enlarged and is not in proportion to the rest of the sketch, since the areas of soil around each root, here considered, are so small that it is impossible to check them by ordinary soil sampling means.)

A second group believes that soil moisture is as readily available near the permanent wilting percentage as it is near the field capacity.

A pear tree on Meyer clay adobe soil near Medford, Ore., was observed to wilt and partially defoliate while the average moisture content of each foot depth of soil and of almost all individual soil samples was well above the permanent wilting percentage.

When this tree showed serous suffering from water shortage, intensive soil moisture sampling showed that no material portion of the root zone was within 3.2% of the permanent wilting percentage.

Some days later the rate of extraction of soil moisture became markedly slower while the average moisture content of each foot depth of soil ranged from 1.7 to 4.2% above the permanent wilting percentage.

Still later, withdrawal of soil moisture at all depths, except for the first foot, ceased before the average content of any foot was depleted to the permanent wilting percentage.

The movement of water through the soil by capillary action was too slow to maintain a uniform condition in large masses of soil.

The roots do not seem to occupy the entire soil mass (4).

The following hypothesis appears to be valid: The soil moisture content of the soil in contact with the feeding roots may be at or near the permanent wilting percentage, while at the same time the moisture content at some distance, perhaps only a few millimeters away, may be much higher thus allowing the average content for an ordinary soil sample to be well above the wilting percentage at the time a tree shows serious distress for need of water.

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EFFECT OF NITROGENOUS FERTILIZERS, ORGANIC MATTER, SULFUR, AND COLLOIDAL SILICA ON THE AVAILABILITY OF PHOSPHORUS IN CALCAREOUS SOILS[1]

H. D. CHAPMAN[2]

RECENT chemical studies (1)[3] have shown that, in general, the calcareous soils of southern California are well supplied in total phosphate and that this phosphate is readily soluble in very dilute acid (0.002 N sulfuric acid); however, it is difficultly available to plants. Results of a similar character have been secured by investigators in other western states (2,3,4). With soils well supplied with difficultly available but readily soluble phosphate, the question arises as to whether the availability of the phosphate can be measurably increased by physiologically acid nitrogen fertilizers, by sulfur, by organic matter, or by other materials such as colloidal silica. Conversely, it is desirable to know whether physiologically alkaline fertilizers decrease phosphate availability. Considerable importance is attached to this problem inasmuch as there are large areas of such soils in the semi-arid regions of the world, many of them being intensively cropped and heavily fertilized with both nitrogen- and phosphate-containing fertilizers.

Although much previous study has been devoted to the question of the effect of many materials on phosphate availability, particularly rock phosphate, insufficient work has been carried out with naturally calcareous soils to warrant general conclusions. It is unnecessary to review the extensive literature of this subject. It suffices to state that in the absence of calcium carbonate, physiologically acid fertilizers, organic matter, sulfur, and colloidal silica have often been shown to increase the availability of rock phosphate and, in some cases, that of the native soil phosphate.

The results of some preliminary studies with calcareous soils are reported in this paper.

EXPERIMENTAL

Three different calcareous soils containing variable amounts of phosphate and calcium carbonate were employed in a series of greenhouse pot tests, Sudan grass being used as the test crop. Each soil was thoroughly mixed, potted in 2-gallon earthenware jars, and differentially treated with equivalent amounts of various nitrogen fertilizers. Also included were various other treatments, such as sulfur, colloidal silica, and organic matter. A uniform treatment of calcium nitrate was given to all of the soils receiving the above non-nitrogenous constituents. The fertilizer materials (c.p. except for the sulfur, colloidal

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[3]Figures in parenthesis refer to "Literature Cited", p. 145.

silica, and organic matter) were thoroughly incorporated with the entire soil mass, the soluble ones being applied in solution. Full details as to the nature and rate of treatments are shown in the tables. The plants were watered throughout with distilled water. When approximately mature, the tops were harvested, dried, and weighed.

The variable yields of Sudan grass resulting from the different treatments are thought to be indicative, in a semi-quantitative way, of the effect of the added materials on phosphate availability. This belief is based on the following lines of evidence:

1. With the soils used (well supplied with total and dilute acid-soluble phosphate), Sudan grass grows very poorly when fertilized with calcium nitrate alone, whereas upon the addition of dicalcium phosphate along with calcium nitrate growth is markedly increased (Figs. 1, 2, and 3). This marked response to phosphate additions denotes then that where nitrogen only is added phosphorus becomes the most limiting factor for good plant growth; hence, any significant increase in growth over that produced by calcium nitrate alone is most logically, though perhaps not conclusively, interpreted as being due to a positive effect of the material added on the availability of the native soil phosphate.

2. The varying yields produced by a given material on the three different soils used in these experiments were in general agreement with theoretical expectation. One of the soils (Table 1) is low in carbonate and high in dilute acid-soluble phosphate; another is higher in carbonate and lower in phosphate; the third is intermediate in carbonate, but very much lower in phosphate. An increase in plant growth resulting from any positive effect of the applied material on phosphate availability should be greatest on the first soil, less on the second, and least on the third. In general, this was found to be true.

TABLE 1.—*Data on soils.*

Soil No.	Soil type	pH	Carbonate as $CaCO_3$, %	Total PO_4 in dry soil, p.p.m.	Water-soluble PO_4 in dry soil, p.p.m.	Acid soluble PO_4* in dry soil, p.p.m.
18758	Yolo clay loam	7.7	0.43	5,080	2.2	2,148
18604	Yolo clay loam	8.3	3.72	6,080	0.6	1,192
18543	Hanford sandy loam	8.2	1.15	2,040	0.2	138

*Determined by the Truog method.

Data showing the pH, carbonate content, and the total water-soluble, and acid-soluble phosphate of the three soils are presented in Table 1. Previous experiments had shown that these three soils are well supplied with potash; hence, none was added. As shown in the tables, the nitrogen was applied at a rate of 300 pounds per acre. Although somewhat heavy, such a rate is not out of line with commercial practice under intensive cropping. Moreover, being thoroughly incorporated with the entire mass of soil in the pots, its concentration was not as great as would result from smaller but more localized field applications.

Statistical treatment of the yield data has shown that differences of less than 10% are not significant.

EFFECT OF NITROGENOUS FERTILIZERS

The effects of equivalent amounts of different nitrogenous fertilizers on the growth and yields of Sudan grass are presented in Fig. 1 and Table 2, respectively.

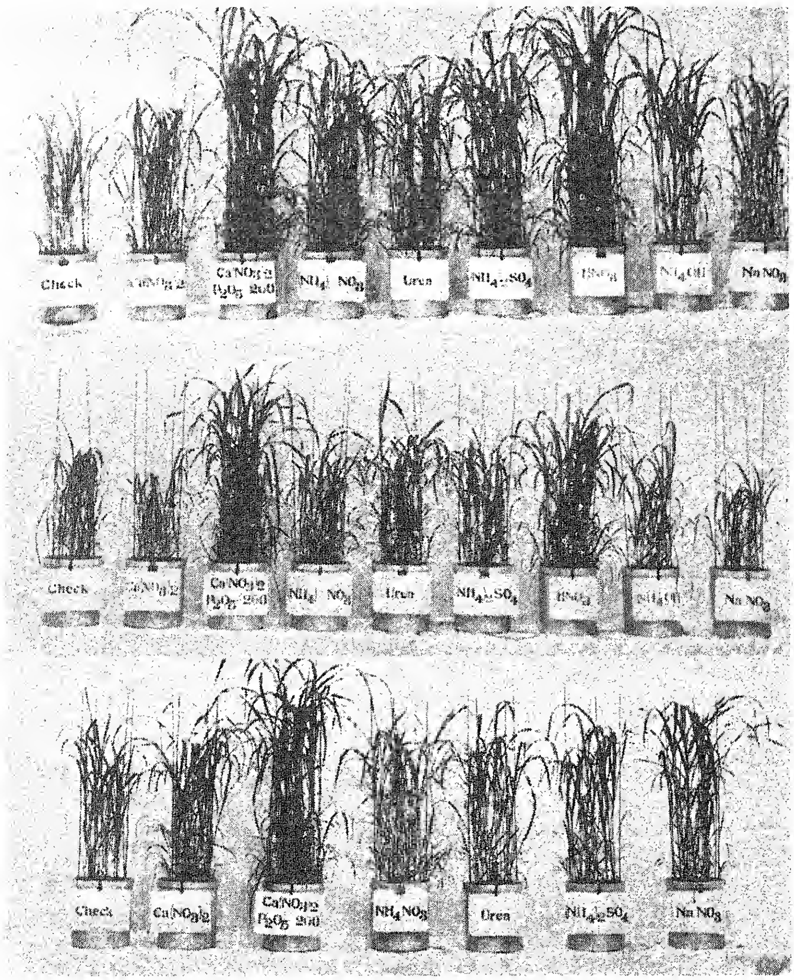

FIG. 1.—Effect of various nitrogenous fertilizers on the availibality of phosphorus in calcareous soils. *Top*, soil No. 18758; low carbonate, high phosphate. *Middle*, soil No. 18604; medium carbonate, medium phosphate. *Bottom*, soil No. 18543; low carbonate, low phosphate.

TABLE 2.—*Effect of various nitrogenous fertilizers on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604			Soil No. 18543		
		Yield			Yield			Yield		
Material	Rate per acre, pounds	Grams* per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams* per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams* per pot	Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	6.2	129.0	7.9	8.6	71.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	4.8	100.0	7.8	12.0	100.0	8.2
$CaH\ PO_4$	50 P_2O_5	11.7	101.0	7.4	11.5	239.0	7.9	9.9	82.0	8.3
$Ca(NO_3)_2$ / $CaH\ PO_4$	300 N / 50 P_2O_5	22.0	189.0	7.4	13.6	283.0	7.9	30.3	252.0	8.2
$Ca(NO_3)_2$ / $CaH\ PO_4$	300 N / 200 P_2O_5	35.3	304.0	7.6	16.7	336.0	7.8	47.4	392.0	8.1
$Ca(NO_3)_2$ / $CaH\ PO_4$	300 N / 600 P_2O_5	46.5	400.0	7.5	19.8	412.0	7.7	54.5	452.0	8.0
$NaNO_3$	300 N	12.3	106.0	7.3	7.1	148.0	8.0	14.7	122.0	8.4
$(NH_4)_2\ SO_4$†	300 N	20.0	172.0	7.4	—	—	—	—	—	—
$(NH_4)_2\ SO_4$‡	300 N	28.8	248.0	7.6	9.6	200.0	8.0	11.4	94.0	8.1
$NH_4\ NO_3$	300 N	18.4	159.0	7.7	8.1	168.0	8.1	11.7	97.0	8.2
Urea	300 N	16.1	139.0	7.5	12.0	250.0	7.8	11.4	94.0	8.2
$H\ NO_3$	300 N	42.4	365.0	7.6	28.2	578.0	7.9	34.5	286.0	8.1
NH_4OH	300 N	12.9	111.0§	8.0	8.1	168.0	7.7	27.3	218.0	8.3

*Dry matter at 60° C. Average of triplicate treatments.
†Applied in solution.
‡Applied as salt.
§Slight crop injury.

It will be noted that the yields resulting from applications of calcium nitrate alone were only slightly greater than the checks in two of the soils and somewhat less on the other soil. Previous work had shown that larger applications of calcium nitrate (400 pounds nitrogen per acre) slightly depressed plant growth on certain phosphate-deficient soils. This probably resulted from decreased phosphate solubility. Hence, the expression of the yields on the basis of calcium nitrate as 100 slightly exaggerates the effects of the other treatments. For example, the yields produced by the sodium nitrate, though relatively better than those secured with calcium nitrate, are thought to possess little or no significance as regards phosphate availability. The reduced yields with calcium nitrate as compared with those from sodium nitrate may possibly measure the extent to which the former has decreased phosphate availability in the different soils.

The greatest effect on growth, aside from that resulting from direct phosphate applications, was produced by nitric acid. Ammonium sulfate, ammonium nitrate, and urea produced significant increases over calcium nitrate on the two high phosphate soils, but were without effect on the low phosphate soil. Significant increases in growth were also obtained with ammonium hydroxide on two of the soils, but at a rate of 300 pounds per acre it was slightly toxic to the plants grown in soil No. 18758.

The increased growth resulting from nitric acid as contrasted with equivalent amounts of nitrogen in the other forms is noteworthy since the base-neutralizing capacity of 1 equivalent of nitrogen as nitric acid is the same as that resulting from the nitrification of ammonium nitrate, urea, and ammonium hydroxide, and only one-half that of ammonium sulfate. The difference is probably due in part to a mass-action effect; for in the nitrification of ammonium compounds only small amounts of acid are produced at any one moment, whereas the entire quantity of nitric acid would be effective immediately. This suggests the possibility that the rate of nitrification of ammonium compounds in soils may be important in determining the magnitude of the immediate effect of phosphate availability.

The results in general indicate that physiologically acid nitrogen fertilizers are capable of increasing the availability of phosphate in calcareous soils. Their effectiveness will be dependent upon the phosphate-calcium carbonate ratio of the soil, the nature of the materials used, and perhaps the rates at which they are nitrified in the soil. Obviously, rate and manner of application will also be important.

EFFECT OF SULFUR AND COLLOIDAL SILICA

The results obtained with sulfur and with colloidal silica alone and in combination with sulfur are presented in Fig. 2 and Table 3.

The most outstanding effect is that produced by sulfur: in soil No. 18758 sulfur applied at a rate of 4,000 pounds per acre gave a yield increase greater than that obtained from phosphate applied at a rate of 600 pounds of P_2O_5 per acre. The effect was also comparatively great on the other two soils.

Colloidal silica slightly increased the yields on two of the soils. The material used was anhydrous and granular (40-mesh and finer),

TABLE 2.—*Effect of various nitrogenous fertilizers on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604			Soil No. 18543		
Material	Rate per acre, pounds	Yield: Grams* per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH	Yield: Grams* per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH	Yield: Grams* per pot	Yield: Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	6.2	129.0	7.9	8.6	71.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	4.8	100.0	7.8	12.0	100.0	8.2
$CaH PO_4$	50 P_2O_5	11.7	101.0	7.4	11.5	239.0	7.9	9.9	82.0	8.3
$Ca(NO_3)_2$ / $CaH PO_4$	300 N / 50 P_2O_5	22.0	189.0	7.4	13.6	283.0	7.9	30.3	252.0	8.2
$Ca(NO_3)_2$ / $CaH PO_4$	300 N / 200 P_2O_5	35.3	304.0	7.6	16.7	336.0	7.8	47.4	392.0	8.1
$Ca(NO_3)_2$ / $CaH PO_4$	300 N / 600 P_2O_5	46.5	400.0	7.5	19.8	412.0	7.7	54.5	452.0	8.0
$NaNO_3$	300 N	12.3	106.0	7.3	7.1	148.0	8.0	14.7	122.0	8.4
$(NH_4)_2 SO_4$†	300 N	20.0	172.0	7.4	—	—	—	—	—	—
$(NH_4)_2 SO_4$‡	300 N	28.8	248.0	7.6	9.6	200.0	8.0	11.4	94.0	8.1
$NH_4 NO_3$	300 N	18.4	159.0	7.7	8.1	168.0	8.1	11.7	97.0	8.2
Urea	300 N	16.1	139.0	7.5	12.0	250.0	7.8	11.4	94.0	8.2
$H NO_3$	300 N	42.4	365.0	7.6	28.2	578.0	7.9	34.5	286.0	8.1
NH_4OH	300 N	12.9	111.0§	8.0	8.1	168.0	7.7	27.3	218.0	8.3

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§Slight crop injury.

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The greatest effect on growth, aside from that resulting from direct phosphate applications, was produced by nitric acid. Ammonium sulfate, ammonium nitrate, and urea produced significant increases over calcium nitrate on the two high phosphate soils, but were without effect on the low phosphate soil. Significant increases in growth were also obtained with ammonium hydroxide on two of the soils, but at a rate of 300 pounds per acre it was slightly toxic to the plants grown in soil No. 18758.

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The results in general indicate that physiologically acid nitrogen fertilizers are capable of increasing the availability of phosphate in calcareous soils. Their effectiveness will be dependent upon the phosphate-calcium carbonate ratio of the soil, the nature of the materials used, and perhaps the rates at which they are nitrified in the soil. Obviously, rate and manner of application will also be important.

EFFECT OF SULFUR AND COLLOIDAL SILICA

The results obtained with sulfur and with colloidal silica alone and in combination with sulfur are presented in Fig. 2 and Table 3.

The most outstanding effect is that produced by sulfur: in soil No. 18758 sulfur applied at a rate of 4,000 pounds per acre gave a yield increase greater than that obtained from phosphate applied at a rate of 600 pounds of P_2O_5 per acre. The effect was also comparatively great on the other two soils.

Colloidal silica slightly increased the yields on two of the soils. The material used was anhydrous and granular (40-mesh and finer),

TABLE 3.—*Effect of sulfur and SiO_2 on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604*			Soil No. 18543*		
		Yield			Yield			Yield		
Material	Rate per acre, pounds	Grams† per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams† per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams† per pot	Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	4.6	143.0	8.1	3.1	129.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	3.2	100.0	8.0	2.4	100.0	8.1
$Ca(NO_3)_2$ $CaH PO_4$	300 N 50 P_2O_5	22.0	189.0	7.4	19.7	615.0	7.9	20.3	845.0	8.3
$Ca(NO_3)_2$ $CaH PO_4$	300 N 200 P_2O_5	35.3	304.0	7.6	23.3	726.0	7.8	31.7	1,320.0	8.1
$Ca(NO_3)_2$ $CaH PO_4$	300 N 600 P_2O_5	46.5	400.0	7.5	28.7	895.0	7.7	36.6	1,520.0	8.0
$Ca(NO_3)_2$ Sulfur	300 N 4,000 S	48.7	419.0	5.6	9.3	290.0	7.3	7.6	316.0	7.4
$Ca(NO_3)_2$ Sulfur Colloidal SiO_2	300 N 4,000 S 5,900 SiO_2	52.2	448.0	5.8	—	—	—	—	—	—
$Ca(NO_3)_2$ SiO_2	300 N 5,900 SiO_2	16.9	145.0	7.5	3.3	103.0	8.0	3.5	146.0	8.0
$Ca(NO_3)_2$ Na_2SiO_3	300 N 950 SiO_2	11.6	100.0	8.0	2.2	69.0	7.9	2.3	96.0	8.2

*Three previous crops of Sudan grass were grown on these soils, the previous pot treatment having been similar but at different rates. The old roots were screened out, the soil leached with distilled water, and subsequently retreated with the materials indicated.
†Dry matter at 60° C. Average of triplicate treatments.

being a commercial product. Although this material exhibited certain colloidal properties, such as heat of wetting and dye adsorption, it is possible that a hydrated form might have had a more pronounced effect. Of possible significance is the yield increase attending its use in combination with sulfur on soil No. 18758.

Sodium silicate was slightly depressive in two soils and without effect on the other. This result is of interest since Scarseth (5) has

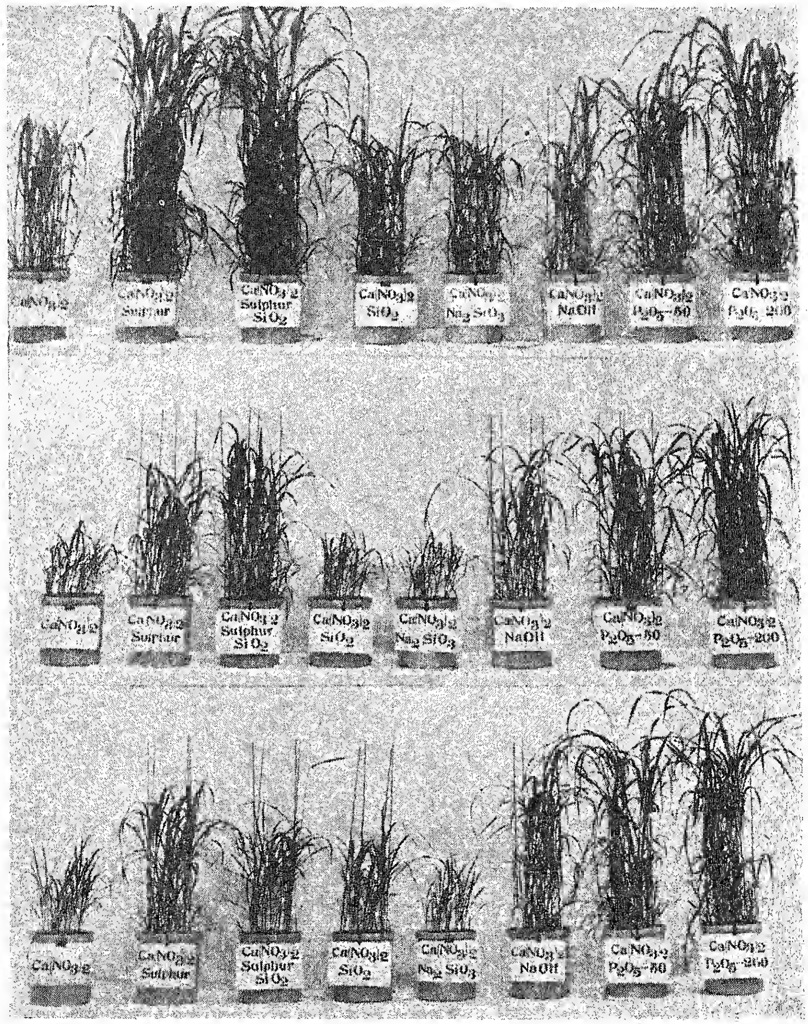

FIG. 2.—Effect of sulfur, colloidal silica, and sodium silicate on the availability of phosphorous in calcareous soils. *Top*, soil No. 18758; low carbonate, high phosphate. *Middle*, soil No. 18604; medium carbonate, medium phosphate. *Bottom*, soil No. 18543; low carbonate, low phosphate.

recently shown that sodium silicate will increase phosphate solubility and availability in certain soils, presumably by virtue of anion exchange. It may be that in calcareous soils no phosphorus is held in exchangeable form.

EFFECT OF ORGANIC MATTER

The results obtained with organic matter are shown in Table 4 and Fig. 3. With filtered paper and nitrogen (each mixed separately with the soil), growth was markedly depressed. Former experiments had given similar results. When phosphate was added, however, the yield obtained was greater than that from the same amount of phosphate without filter paper. It appears that the depressive effect of filter paper when used without phosphate was due to the competition for soluble phosphate between the cellulose-decomposing organisms and the Sudan grass. The increased growth resulting from the filter paper and phosphate combination over the phosphate alone is indicative of a favorable influence on phosphate solubility occasioned, presumably, by decomposition products of the cellulose.

With ground barley straw substantial growth increases were secured. However, it is certain that a part, at least, of these increases resulted from the phosphate of the straw. Nearly two-thirds of the total phosphate of the barley appeared in a water extract as inorganic phosphate, and some of this was, of course, immediately available. With soil No. 18758 the application of phosphate in combination with barley straw produced no better effect than phosphate alone, while with soil No. 18604 the result was somewhat better. There is no definite evidence, therefore, of a beneficial influence from the barley straw other than that which can be ascribed to its own phosphorus content.

Although entirely preliminary in nature, the work with the organic materials indicates the importance of the phosphorus-carbon ratio and the possibility that with a favorable ratio, phosphate availability may be increased through the solvent action of the products of decomposition. Much more work is needed to determine the relative importance of the various factors that come into play when organic materials are applied to soils.

DISCUSSION

Under the conditions of these tests physiologically acid nitrogen fertilizers and sulfur increased the availability of phosphate in calcareous soils. The practical application of these results, however, must await further investigation. Under field conditions, the zone in which the materials are incorporated in relation to that of the absorbing roots of crops will, of course, be important. Since ammonium ions are fixed by the base-exchange components of soils, it is improbable that there will be much movement downward of this form of nitrogen; hence, its solvent effect will be limited largely to the zone of incorporation. The effect of sulfur and organic matter will likewise be confined largely to surface layers unless special methods of deep incorporation are employed.

Under irrigation agriculture, the composition of the irrigation water will be a factor of some consequence. Most waters contain more or

TABLE 4.—*Effect of filter paper and barley straw on phosphate availability in calcareous soils as measured by the yield of Sudan grass.*

Treatment		Soil No. 18758			Soil No. 18604*			Soil No. 18543		
		Yield			Yield			Yield		
Material	Rate per acre, pounds	Grams† per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams† per pot	Based on $Ca(NO_3)_2$ as 100	Final pH	Grams† per pot	Based on $Ca(NO_3)_2$ as 100	Final pH
None	—	9.0	77.0	7.5	4.6	143.0	8.1	3.1	129.0	8.3
$Ca(NO_3)_2$	300 N	11.6	100.0	7.4	3.2	100.0	8.0	2.4	100.0	8.1
$Ca(NO_3)_2$, CaH PO_4	300 N, 50 P_2O_5	22.0	189.0	7.4	19.7	615.0	7.9	20.3	845.0	8.2
$Ca(NO_3)_2$, CaH PO_4	300 N, 200 P_2O_5	35.3	304.0	7.6	23.3	726.0	7.8	31.7	1,320.0	8.1
$Ca(NO_3)_2$, CaH PO_4	300 N, 600 P_2O_5	46.5	400.0	7.5	28.7	895.0	7.7	36.6	1,520.0	8.0
$Ca(NO_3)_2$, Ground filter paper	300 N, 1910 carbon	—	—	—	—	—	—	1.4	58.0	8.0
$Ca(NO_3)_2$, Ground filter paper, CaH PO_4	300 N, 1910 carbon, 200 P_2O_5	—	—	—	—	—	—	43.4	1,810.0	8.2
$Ca(NO_3)_2$, Ground barley straw	300 N, 1,950 carbon, 79.0 P_2O_5	23.0	198.0	7.4	18.1	565.0	7.9	—	—	—
$Ca(NO_3)_2$, Ground barley straw, CaH PO_4	300 N, 1,950 carbon, 79.0 P_2O_5, 200 P_2O_5	34.6	298.0	7.4	27.0	844.0	7.6	—	—	—

*Three previous crops of Sudan grass were grown in these soils, previous pot treatment having been similar but at different rates. The old roots were screened out, the soil leached with distilled water, and subsequently retreated with the materials indicated.

†Dry matter at 60° C. Average of triplicate treatments.

less calcium, bicarbonate, and hydroxyl ions; consequently, they will counteract to some extent the solubilizing effect of acid-forming materials.

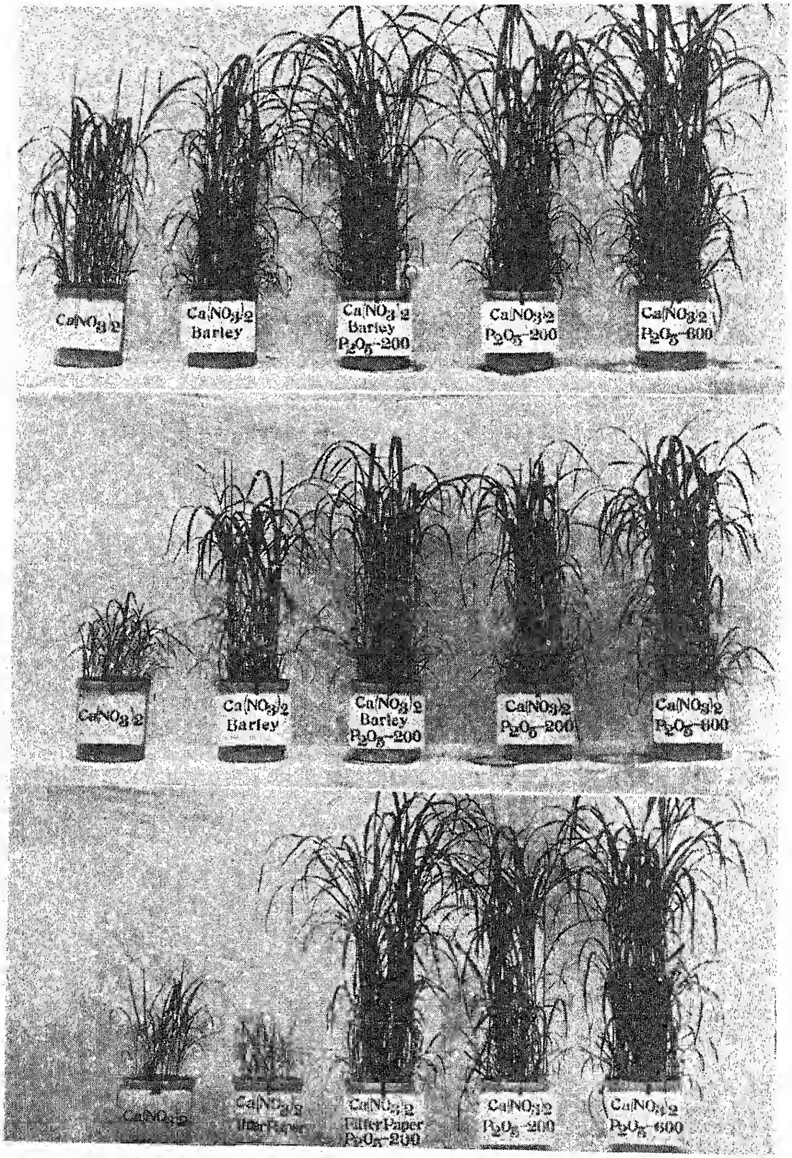

FIG. 3.—Effect of barley straw and filter paper on the availability of phosphorus in calcareous soils. *Top*, soil No. 18758; low carbonate, high phosphate. *Middle*, soil No. 18604; medium $CaCo_3$, medium phosphate. *Bottom*, soil No. 18543; low carbonate, low phosphate.

The efficacy of any given material will obviously be influenced by the relative amounts of carbonate and phosphate in the soil. The soils studied were relatively low in calcium carbonate (3.7% or less) and moderately well supplied with phosphate. Many semi-arid soils contain much greater quantities of carbonate; hence, further work is needed to determine more definitely the influence of the carbonate-phosphate ratio. Fineness of division of the carbonate and the nature of the dominant phosphate compounds may also be important.

SUMMARY

Pot culture studies with Sudan grass to determine the effect of various nitrogenous fertilizers, sulfur, colloidal silica, and organic matter on the availability of phosphorus in three calcareous soils have shown the following:

1. Physiologically acid nitrogen fertilizers increased phosphate availability, the magnitude of the effect being related to the carbonate-phosphate ratio of the soil and the nature of the materials used.

2. Sulfur markedly increased phosphate availability in all of the soils studied, being particularly effective on a soil low in carbonate and high in phosphate.

3. Colloidal silica slightly increased phosphate availability.

4. Sodium silicate was without effect.

5. Filter paper added without phosphate applications depressed the yields of Sudan grass presumably as a result of the competition for phosphate between cellulose-decomposing organisms and the plants. When filter paper was supplemented by phosphate, the yields were greater than those obtained with phosphate alone, indicating that carbon dioxide or other decomposition products of the filter paper increased phosphate availability. On the other hand, no effects were obtained from ground barley straw other than those which might be ascribed to the phosphorus it supplied.

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THE FIXATION OF POTASH BY MUCK SOILS[1]

G. H. ENFIELD AND S. D. CONNER[2]

MUCK soils as a rule are naturally deficient in potash or soon become so when cropped. This makes it necessary to apply potash fertilizers to maintain high crop yields. The amount, kind, and placement of the fertilizer not only depends upon the crop needs but also upon the soil characteristics. The affinity of certain soils for soluble phosphate has prompted some investigators (2, 15)[3] to recommend that it should be applied in a restricted area near the seed. Other investigators (5) have found that under intensive cropping conditions a sufficient amount of potash cannot be safely placed near the seed without some danger of reducing germination. Since fixation can be either beneficial or detrimental, the most desirable method of applying fertilizer depends partially on the degree to which it is fixed.

In a study on low moor soils, Krugel, Dreyspring, and Heinerich (6) found that, in certain cases, the absorptive fixation of potash salts caused by the action of humic substances was very great. It was so great that 267 pounds of K_2O per acre were insufficient to produce good crops and it was necessary to make an additional application of one-half the original quantity before barley would grow normally. Such evidence would indicate that muck soils of this country might possess high potash-fixing ability.

Volk (16), in his work on several mineral soils, found that by using single extractions with dilute salt solutions or even weak acids, it was impossible to remove all of the potassium he had applied, if the soils had been either dried or dried and heated after the addition of potash salts. He concluded that a portion of the potash was converted into muscovite which is only slowly soluble.

Likewise, Frear and Erb (4) found that a portion of the potash applied to Hagerstown silt loam on the Pennsylvania State College fertility field was fixed in a form that could not be leached out in a short time nor cropped out in a season.

McCool (8) claims that mucks with the greatest amount of mineral matter show the greatest fixation. Others (3, 7, 9, 10) think that the acidity may be an important factor affecting the fixation of potash.

Fixation studies have usually been made by chemical methods. The assumption is then made that such a chemical measure of potash fixation is a good indication of the amount of potash which is unavailable to plants.

The study reported here was made in the greenhouse by growing four crops in pots fertilized with potassium chloride by two methods, *viz.*, in a layer and mixed with all of the soil. The difference in the

[1]Contribution from the Department of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Indiana. Also presented at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935. Received for publication December 14, 1935.

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[3]Figures in parenthesis refer to "Literature Cited", p. 155.

amount of potash removed by the plants from the soil fertilized by the two methods was determined. Neubauer studies were made to determine the amount of available potash in the mucks before and after growing the four crops. The effect of these two levels of fertility was also noted on the seedling's ability to remove small amounts of additional potash with and without lime.

DESCRIPTION OF SOILS

Soil No. 10 is a loose, brown, fibrous muck which had been overdrained but well fertilized for two seasons. Neither crop was harvested due to crop failure.

Soil No. 20 is a black, well-decomposed muck from a field on which potatoes and corn had been grown for a long time. High yields had been maintained by large applications of fertilizer high in potash.

Soil No. 30 is a black muck similar to No. 20 with the exception that it was from the untreated plat at the Pinney-Purdue Muck Experiment Field near Wanatah. The yields from this plat indicate that it was in a very low state of fertility.

Soil No. 40 is a black, well-decomposed calcareous muck. Although the particular part of the field from which this sample was taken had received large applications of fertilizer and careful management, it had failed to produce profitable yields of onions. Later it was found that the addition of both copper and manganese was needed before good crops could be grown on this soil.

Soil No. 50 is a brown, peaty muck, very acid and high in ash content. A heavy application of clay had been applied the year before the sample was procured.

A brief chemical description of each soil is reported in Table 1.

METHODS AND PLAN OF EXPERIMENT

The moisture-holding capacity of the mucks was determined in tubes having perforated bottoms by saturating air-dry samples with distilled water. The saturated mucks were allowed to drain for about 5 minutes, then the tubes were wiped dry and weighed. The moisture-holding capacity recorded in Table 1 is the amount of water remaining in 100 grams of moisture-free muck.

The exchangeable bases were determined by the method described by Schollenberger and Dreibelbis (12) with the exception that 10 grams of muck were leached with 350 ml. neutral ammonium acetate instead of the usual quantity. The results were calculated to milli-equivalents of the bases per 100 grams of moisture-free muck.

The elements soluble in 0.2 normal nitric acid were determined by digesting 1 part air-dry muck with 10 parts of the acid at room temperature for 24 hours.

The Neubauer results were determined by the method used by Thornton (14) except that 33⅓ grams of muck instead of 100 were used. The moisture was maintained at 50% of the soil's water-holding capacity.

All of the potassium determinations on the soils were made by the A.O.A.C. chloroplatinate method. The potash in the plant ash was determined by the perchloric acid method described by Scott (13), except that a Whatman No. 42 filter paper was used instead of asbestos. After the paper had been dried free of alcohol it was placed in a funnel. The potassium perchlorate washed through with hot water into a tared dish, evaporated to dryness on a steam bath, and weighed after 1½ hours of ignition at 300° C. This is a modification of the method by Baxter and Rupert (1), which is very rapid and gives concordant results.

TABLE 1.—*Chemical description of the muck soils used in the experiment on moisture-free basis.*

Soil No.	Loss on ignition %	Insoluble matter in 1.115 Sp. Gr. HCl %	Moisture-holding capacity, grams H_2O per 100 grams of muck	Milligram-equivalents of exchangeable elements per 100 grams of moisture-free soil				Soluble in N/5 HNO_3				Neubauer, mg. K_2O*	K availability†	P availability†	pH
				Total bases	H	Ca	K	P_2O_5 %	CaO %	Mn_3O_4 %	K_2O %				
10	86	6.7	571	126	33	75	4.0	0.03	2.7	0.025	0.08	30	H+	M—	5.2
20	76	13.5	250	140	9	106	2.4	0.06	3.2	0.015	0.09	35	H++	H++	5.9
30	69	19.2	195	113	26	67	0.7	0.014	2.7	0.028	0.014	6	O	L	5.3
40	76	8.25	299	147	0	143	1.4	0.035	5.2	0.017	0.035	15	M	H++	8.0
50	50	44.0	253	71	30	32	0.8	0.04	1.0	0.013	0.03	11	L	L—	4.5

*Neubauer results are based on 33⅓ grams of moisture-free muck.
†Determined by method described in Purdue Univ. Circ. 204. H = high; M = medium; L = low.

In the early fall of 1932 each of the previously described mucks was brought to the greenhouse, allowed to dry partially, and then thoroughly mixed. Six 6-gallon earthenware jars were filled to within about 2 inches of the top with each soil. The great variation in weight of the different mucks made it impractical to use the same weight of muck in all pots; however, the weight of each soil was the same in each of the six pots containing that soil.

All pots were fertilized with 4 grams of ammonium nitrate and 6 grams of mono-calcium phosphate mixed uniformly with the soil. Two of the pots of each muck so treated were designated as treatment 1; two, designated as treatment 2, were fertilized in addition with 4 grams of potassium chloride mixed completely with all the soil; while the remaining two pots, designated as treatment 3, were treated with the same amount of potassium chloride as in treatment 2 except that it was applied in a layer 3 inches below the surface. The potash treatments were equivalent to 320 pounds KCl per acre 6 inches. Later it was found necessary to add more nitrates, therefore 3 grams of calcium nitrate were added to each of the pots with soil No. 50 and 1½ grams to each of the remaining pots. Distilled water was added to all of the pots to 80% of the moisture-holding capacity, which is considered to be ideal by Tacke (6). Later this amount was cut down to 50% because the muck was thought to be too wet for good plant growth, although little growth difference was noticed.

RESULTS

Barley was planted in December and harvested in May. The average air-dried yield and potash content of plants per pot is recorded in Table 2.

TABLE 2.—*Effect of potassium chloride on growth and potassium content of barley.*

Soil No.	Treatment No.	Treatment Location	Average dry weight per pot, grams	K_2O, dry weight basis, %	K_2O removed per pot, grams	K_2O added, grams	Average loss of K_2O per pot, grams	Loss or gain of K_2O per pot due to treatment, grams
10	1	Without potash	129.5	2.18	2.8	—	—2.8	—
	2	Potash mixed	149.0	3.83	5.7	2.5	—3.2	—0.4
	3	Potash in a layer	148.5	3.35	4.8	2.5	—2.3	+0.5
20	1	Without potash	161.5	2.79	4.5	—	—4.5	—
	2	Potash mixed	174.5	4.18	7.3	2.5	—4.8	—0.3
	3	Potash in a layer	162.5	3.18	6.2	2.5	—3.7	+0.8
30	1	Without potash	77.5	1.18	0.9	—	—0.9	—
	2	Potash mixed	137.0	2.41	3.3	2.5	—0.8	+0.1
	3	Potash in a layer	140.0	2.65	3.7	2.5	—1.2	—0.3
40	1	Without potash	56.0	2.65	1.5	—	—1.5	—
	2	Potash mixed	51.0	5.97	3.0	2.5	—0.5	+1.0
	3	Potash in a layer	56.0	5.03	2.8	2.5	—0.3	+1.2
50	1	Without potash	107.0	1.96	2.1	—	—2.1	—
	2	Potash mixed	122.0	3.38	4.1	2.5	—1.6	+0.5
	3	Potash in a layer	137.0	3.55	4.6	2.5	—2.1	+0.0

Since in all cases more potash was recovered than applied, it would seem that the soil was already well supplied with potash. Because of this high potash level a crop of tomatoes was grown to deplete the soils more thoroughly of their available potash. The plants were started in flats, later transferred to individual 4-inch pots, and were then heavily fertilized with nitrogen and phosphorus. When the tomato plants were about 8 inches high the soil was washed free from the roots and two plants were set into each of the 6-gallon pots in the experiment. Each plant was kept pruned to one terminal bud and all side branches thrown away.

The crop was harvested when the temperature of the greenhouse, due to summer heat, became unfavorable for good growth. The tomatoes were not analyzed, but a record of the yield of fruit was kept (Table 3). The tomato crop was of value largely in that it helped bring the available potash to a lower level.

TABLE 3.—*The effect of potassium chloride on the growth of tomatoes.*

Soil No.	Average fresh weight of fruit per pot, grams			Average increase due to potash	Increase for layer over mixed
	Without potash	With potash mixed with soil	With potash in a layer		
10	292	539	558	+257	+ 19
20	686	788	799	+107	+ 11
30	330	430	509	+140	+ 79
40	547	550	665	+ 60	+115
50	464	510	457	+ 20	— 53

In the fall of 1933 the soils were tested for water-soluble and exchangeable K_2O and all were found to be very deficient. It made little difference whether or not they had been treated previously with potash.

The dry mucks were moistened with distilled water and refertilized exactly as at the beginning of the experiment. Spinach, a cool season crop, was planted in early winter. This crop was found to be very sensitive to potash deficiency, as shown by yields in Table 4. The plants on soil No. 50 without potash died before those on treatments 2 or 3 reached maturity. The spinach was harvested at two dates. The best two plants out of each pot were harvested on March 15 and the remainder of the plants on March 27. All of the air-dry plants from each treatment were ground in a Wiley mill and analyzed for K_2O.

From Table 4 it may be noted that in all cases the most potassium was removed by the spinach where the KCl was applied in a layer. To find whether this was due to unfavorable fixation or merely because of the poor root system of spinach, a crop with a good root system was next tried. Since Sudan grass grows well in high temperatures and has a good root system, it was selected further to deplete the potash from the muck after the spinach crop had been harvested.

When the Sudan grass was about one-half grown, it could be seen that those plants fertilized in a layer were larger than those supplied with potash mixed with all the soil; although in both cases the potash

TABLE 4.—*Effect of potassium chloride on growth and potash content of spinach.*

Soil No.	Treatment		Average fresh weight, grams	Average dry weight per pot, grams	K_2O, dry weight basis, %	K_2O removed per pot, grams	K_2O added, grams	Net loss or gain of K_2O per pot, grams	Residual K_2O over untreated
	No.	Location							
10	1	Without potash	2.25	0.57	1.22	0.07	—	—0.07	—
	2	Potash mixed	162.0	15.3	10.05	1.54	2.50	+0.96	+1.03
	3	Potash in a layer	244.0	20.0	9.82	1.84	2.50	+0.66	+0.73
20	1	Without potash	58.5	6.8	2.17	0.15	—	—0.15	—
	2	Potash mixed	241.0	21.3	7.95	1.68	2.50	+0.82	+0.97
	3	Potash in a layer	249.0	21.9	8.75	1.92	2.50	+0.58	+0.73
30	1	Without potash	2.5	0.52	1.73	0.09	—	—0.09	—
	2	Potash mixed	262.5	19.1	6.02	1.15	2.50	+1.35	+1.44
	3	Potash in a layer	265.0	25.0	7.65	1.91	2.50	+0.59	+0.68
40	1	Without potash	4.0	0.87	1.42	0.12	—	—0.12	—
	2	Potash mixed	121.5	10.3	9.54	0.98	2.50	+1.52	+1.64
	3	Potash in a layer	140.5	10.5	10.22	1.07	2.50	+1.43	+1.55
50	1	Without potash	—	—	—	—	—	—	—
	2	Potash mixed	271.0	21.3	8.49	1.81	2.50	+0.69	+0.69
	3	Potash in a layer	276.0	22.5	8.31	1.87	2.50	+0.63	—

greatly increased the growth. The average yield in grams and the potash content is shown in Table 5. The potash removed by Sudan grass, like that in spinach, was in all cases greater in treatment 3 than in treatment 2, indicating some unfavorable fixation.

TABLE 5.—*Effect of potassium chloride on the growth and potash content of Sudan grass and net loss or gain of potash per pot due to treatment.*

Soil No.	Treatment No.	Treatment Location	Average dry weight per pot, grams	K_2O, dry weight basis, %	K_2O removed per pot, grams	Net residual K_2O after spinach, grams	Residual K_2O over treatment 1 after Sudan grass, grams
	1	Without potash	49.0	0.58	0.28	—	—
10	2	Potash mixed	146.0	0.50	0.73	1.03	+0.58
	3	Potash in a layer	158.0	0.62	0.98	0.73	+0.03
	1	Without potash	98.0	0.58	0.57	—	—
20	2	Potash mixed	166.0	0.71	1.18	0.97	+0.36
	3	Potash in a layer	167.0	0.87	1.45	0.73	—0.13
	1	Without potash	88.0	0.46	0.40	—	—
30	2	Potash mixed	145.0	0.71	1.03	1.44	+0.81
	3	Potash in a layer	160.0	0.66	1.06	0.68	+0.02
	1	Without potash	28.0	0.90	0.25	—	—
40	2	Potash mixed	35.0	2.91	1.02	1.64	+0.93
	3	Potash in a layer	38.0	2.88	1.09	1.55	+0.71
	1	Without potash	66.0	0.62	0.41	—	—
50	2	Potash mixed	167.0	0.57	0.95	0.69	+0.15
	3	Potash in a layer	187.0	0.54	1.01	0.63	+0.03

The Neubauer (11) method is a means by which the amount of phosphorus and potassium available to plants in any given soil can be estimated. If one should estimate the amount present in any soil and then add a small quantity of potash in an available form, it should be recovered in addition to the amount supplied by the soil, provided that other soil factors are favorable and that the sum of the amount added and that already in the soil is not greater than the absorptive capacity of the plants.

Three sets of duplicate Neubauer tests were started on each soil. One set was run on each original soil without treatment; another with 25 mg of additional K_2O in the form of potassium chloride; and the third with 25 mg of K_2O plus 0.56 gram CaO.

Each muck mixed with 50 grams of sand was uniformly moistened and dried, then again moistened and air dried to give the potash a chance to react with the soil.

From the results of the previous pot tests, it might be expected that potash fixation would be greater in potash-deficient than in high potash mucks, therefore the second set of Neubauer tests was run on soils which had grown four successive crops without added potash. These mucks were all very much depleted of available potash, as shown in Table 6. It may be noted that the Neubauer potash is

lower in the cropped soils than in the original soil. The percentage of added potash recovered, however, is greater from the cropped than from the original soils, with the exception of soil No. 50 which is the one high in ash, indicating that the potash present in the uncropped soil approached the absorptive capacity of the rye seedlings and that some unfavorable fixation might have taken place in soil No. 50.

TABLE 6.—*Milligrams of K_2O extracted from the muck by Neubauer method before and after four greenhouse crops were removed.*

Soil No.	Untreated soil		Soil+25 mgms K_2O		Soil+25 mgms K_2O+ 1 gram $CaCO_3$		Mgms K_2O applied that were recovered			
							Without $CaCO_3$		With $CaCO_3$	
	Un-cropped	Cropped	Un-cropped	Cropped	Un-cropped	Cropped	Un-cropped	Cropped	Un-cropped	Cropped
10	29.6	3.3	49.7	24.5	50.0	27.9	20.1	21.2	20.4	24.6
20	34.5	3.2	52.3	23.8	51.6	26.2	17.8	20.6	17.1	23.0
30	6.0	5.6	27.2	26.8	26.1	27.0	21.2	21.2	20.1	21.4
40	15.2	5.1	35.0	28.4	35.0	27.3	19.8	22.3	19.8	22.3
50	10.6	4.8	28.6	18.0	30.5	24.2	18.0	13.2	19.8	19.4

In studies of phosphate fixation by soils, it has been found that the amount fixed depends partially upon the amount of soil within reactable distance of the soluble phosphate. Conditions should then be more favorable for fixation of potassium if it were applied by mixing it with the entire pot of soil than if applied in a layer a few inches below the surface.

Barley, the first greenhouse crop, removed 0.4 and 0.3 gram more K_2O, respectively, from soils Nos. 10 and 20 than could be accounted for by adding the amount of potash removed from the untreated soil and the amount supplied by the 4 grams of potassium chloride mixed with all the soil. However, this may be due to a stimulation of root growth in mucks treated with potash. It would also indicate that the barley on these soils was more able to extract a given quantity of potash if distributed through the entire pot than if it were confined to a restricted area below the seed.

The other three soils responded inversely to soils Nos. 10 and 20. Neubauer tests, the amount of K_2O soluble in 0.2 normal HNO_3, crop yields, and the Indiana rapid tests all indicate that soils Nos. 10 and 20 were very high in available K_2O. This implies that both of these soils were already supplied with soluble K_2O and any additional amount of soluble potassium would probably not be adversely fixed.

Barley removed more potash from the soil than was applied. Tomatoes, which followed, further depleted the available potash to a very low level.

Spinach, the first crop after the depleted mucks were refertilized, removed on the average 0.25 gram more K_2O from the pots fertil-

ized with potassium chloride placed in a layer than with it mixed with all of the soil. After the spinach, the potash content of the soils was greatest in pots with treatment 2, but the following crop, Sudan grass, failed to remove as much potash from this treatment as it did from treatment 3.

The roots of the Sudan grass were numerous and extensive. After the plants were harvested and the soil became dry, one could remove the entire mass of roots and soil from the pot in one lump. After cutting this lump into thin slices no difference could be detected nor any localization of roots found at the zone where the layer of potash had been applied. The Sudan grass was tested for available potash by the Indiana plant tissue test and found to be very low in potash. Since the root system of the crop was good and the plants were capable of removing more potash from the soil had it been available, it would indicate that there was some fixation of potash by the depleted soils where it was applied mixed with the entire pot.

Neubauer results show that there was as much as 2.3 mgms of K_2O difference between the five mucks after the removal of four greenhouse crops. Soil No. 20, which contained the largest amount of available K_2O before cropping, had become the lowest in available potash after the removal of the greenhouse crops.

The effect of lime was found to be greatest on the most acid soils and there was a tendency to remove more potash in the presence of lime than in its absence. If lime had caused any fixation of the potash, it was more than overcome by some other effect it had on the plant. The soil with the most mineral matter caused the greatest amount of fixation and inversely the one with the least inorganic matter caused the least fixation. The addition of lime to the muck which was already calcareous did not show any change.

Since on the average only 80.7% of the potassium applied in the Neubauer experiments was recovered, it would indicate that there was some fixation of potash by muck soils as measured by this method.

SUMMARY

1. Five mucks, widely different in reaction, composition, and previous treatment, were tested in pots for potash fixation by growing four crops with three different treatments, *viz.*, without potash, with potash mixed with the entire pot of soil, and with potash applied in a layer beneath the seed.

2. More potash was recovered and larger yields were procured from pots of potash-deficient mucks treated with potash in a layer than from those with the potash mixed with all the soil.

3. In the case of mucks well supplied with potash, larger yields and more potash were obtained from the pots treated with the potassium chloride mixed with all the soil than from those with potash applied in a layer.

4. Fixation of 25 mgms of applied potash per 33⅓ grams of muck was studied by the Neubauer method before and after four greenhouse crops were removed without the addition of any potash fertilizers.

5. Larger amounts of the applied potash were recovered by the Neubauer method from potash-deficient soils than from those well supplied.

6. In the Neubauer studies, lime did not cause any appreciable fixation of potash.

7. On the very acid and potash-deficient mucks more potash was removed by the plants in the presence of additional lime than without the addition of lime.

8. There was a close correlation between exchangeable potassium, Neubauer results, and the response of plants in pots to potash fertilization.

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A COMPARISON OF WINTER LEGUME GREEN MANURE AND NITRATE OF SODA FOR FERTILIZING COTTON[1]

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IN recent years, farmers in the southeastern part of the United States have been increasing their acreage in vetches, Austrian peas, crimson clover, and other winter-growing legumes for use as green manure in fertilizing cotton and other spring-planted crops. This part of the cotton belt uses more commercial fertilizers than any other area in the United States, especially nitrogenous fertilizers. The experiment reported here was conducted to compare the value of vetch and Austrian peas with nitrate of soda for fertilizing cotton where cotton is grown continuously on the same land as is the custom on many cotton farms.

MATERIALS AND METHODS

Hairy vetch was planted on the winter legume plats during 1927 to 1931 and Austrian winter peas from 1931 to 1935, inclusive. The winter legume seeds were sown about the middle of October and a good growth, at least 1 ton of air-dry material per acre, was turned under 2 weeks before applying the fertilizers and planting the cotton the latter part of April each spring.

All the plats were fertilized with 600 pounds per acre of 16% superphosphate in the fall of 1927 when the experiment was started. Beginning in the spring of 1928, an annual application of 600 pounds per acre of superphosphate and 64 pounds per acre of muriate of potash was made when the cotton was planted. The nitrate of soda was applied with the other materials and bedded on at planting time. The experiment was conducted on a rather poor phase of Cecil sandy loam soil which is typical of a large area of the Piedmont Soil Province.

Seven series of systematically replicated six-row plats 90 feet long were used for each treatment. Only the four inside plat rows, or 1/34.6 acre, was harvested for yields. The total numbers of plants and hills were counted on the inside rows at picking time.

EXPERIMENTAL RESULTS

The 8-year average yield results in Table 1 show that vetch or Austrian peas turned under produced 93 more pounds of seed cotton per acre than 100 pounds of nitrate of soda per acre. The average yields of the green manure plats were better than those of the plats receiving 100 pounds of nitrate of soda, but not as good as those receiving 200 pounds of nitrate of soda. The green manure plats outyielded the 100-pound nitrate of soda plats every year except one.

Nitrate of soda used at the rate of 200 pounds per acre gave an acre yield increase of 110 pounds of seed cotton over the green manure treatment for the 8-year period, but approximately two-thirds of this

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TABLE 1.—*Pounds of seed cotton per acre produced on winter legume green manure and nitrate of soda treatments at the Georgia Experiment Station, 1928–35.*

Acre treatment*	Pounds of seed cotton per acre								
	1928	1929	1930	1931	1932	1933	1934	1935	8-yr. average
100 pounds nitrate of soda	844	858	897	1,072	896	924	1,145	969	951
200 pounds nitrate of soda	1,129	1,000	997	1,065	941	955	1,872	1,270	1,154
Green manure	1,057	786	1,009	1,133	936	1,085	1,160	1,187	1,044
Green manure and 100 pounds nitrate of soda	1,145	879	1,022	1,247	978	1,077	1,538	1,300	1,148
Green manure and 200 pounds nitrate of soda	1,057	897	915	1,172	882	971	1,638	1,303	1,104

*All treatments received 600 pounds superphosphate and 64 pounds muriate of potash.

increase resulted from the 1934 yield when the commercial nitrogen made an unusually good showing. The 6-year (1928–33 inclusive) results show no significant difference in the value of the two treatments.

Supplementing the green manure with 100 pounds of nitrate of soda produced an increase in yield of 104 pounds of seed cotton per acre over green manure alone. Increasing the nitrogen to 200 pounds of nitrate of soda per acre decreased the yield, probably due to too rank a growth of the cotton, and reduced stands.

There appears to be no marked difference in the cumulative effect of the two treatments, as measured by the difference between the average yields of the first and last 2-year periods of the experiment.

A comparison of the stands as measured by both the number of plants and hills at picking time, as given in Table 2, shows no significant differences between the stands on the treatments except where both green manure and the heavier application of nitrate of soda resulted in fewer plants and hills than the other plats.

SUMMARY AND CONCLUSIONS

An 8-year field experiment was conducted on Cecil sandy loam soil at the Georgia Experiment Station in which winter legume green manure, nitrate of soda, and a combination of green manure and nitrate of soda were compared for fertilizing cotton.

Hairy vetch and Austrian pea green manure turned under 2 weeks before planting cotton produced slightly larger cotton yields than 100 pounds per acre of nitrate of soda applied when the cotton was planted.

Treatments comparing 200 pounds per acre of nitrate of soda and a winter legume green manure crop for fertilizing cotton showed an 8-year average difference of 110 pounds seed cotton per acre in favor of the commercial nitrate.

TABLE 2.—*Number of plants and hills per acre at picking time on green manure and nitrate of soda treatments, 1929-35.*

Acre treatment*	1929		1930		1931		1932		1933		1934		1935		7-yr. Av.	
	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre	No. plants per acre	No. hills per acre
100 pounds nitrate soda....	12,283	9,233	17,611	7,801	17,231	9,116	17,854	10,860	17,715	10,652	22,871	11,631	22,687	10,905	18,322	10,028
200 pounds nitrate soda....	16,919	11,292	14,843	6,621	14,567	8,057	15,120	10,091	16,020	10,299	21,763	11,119	23,867	11,136	17,586	9,802
Green manure...	15,639	9,780	17,231	8,178	15,605	8,628	17,508	10,939	19,030	11,164	20,656	11,154	14,404	8,932	17,153	9,825
Green manure... and 100 pounds nitrate soda....	14,878	9,815	16,349	7,540	13,667	7,912	15,449	10,177	17,248	10,460	20,587	11,194	13,785	8,564	15,995	9,380
Green manure... and 200 pounds nitrate soda....	14,342	9,614	12,975	6,474	11,712	7,189	14,411	9,561	15,362	9,811	20,241	11,012	14,826	9,050	14,838	8,959

*All treatments received 600 pounds superphosphate and 64 pounds muriate of potash.

Supplementing the green manure with 100 and 200 pounds of nitrate of soda per acre increased yields over green manure alone as cotton fertilizer.

Stands, as shown by both the total number of plants and hills per acre at picking, were slightly better on the green manure and nitrate of soda alone treatments than on the other treatments where both fertilizers were used.

NOTES

EFFECT OF DIFFERENT VARIETIES OF SORGHUM ON BIOLOGY OF THE CHINCH BUG

DURING the last several years the effects of chinch bugs (*Blissus leucopterus* Say) feeding on different sorghum and corn varieties studied at the U. S. Dry Land Field Station, Lawton, Okla., in cooperation with the Kansas Agricultural Experiment Station, have shown that the milos are very susceptible to chinch bug injury, that the feteritas are somewhat less susceptible, and that the kafirs and sorgos in general are rather resistant. In 1935, experiments were planned in cooperation with the Oklahoma Agricultural Experiment Station to study the effect of different varieties of sorghum on the biology of the chinch bug. Representative varieties of the above groups were selected for this study. The highly susceptible Dwarf Yellow milo was chosen as a typical variety of the milo group. Common feterita, which is slightly less susceptible than Dwarf Yellow milo under field conditions, represented the feterita group. Blackhull kafir was used as the typical kafir variety. Atlas sorgo, a highly resistant variety, was selected as a representative of the sorgo group.

Seedling plants of Atlas sorgo and Dwarf Yellow milo were used in studies to determine the effect of the host plant on the oviposition of overwintered females and also on the rate of development of first-generation nymphs. Overwintered adults were collected from a field of barley and placed in cages with these varieties for food. Individual oviposition records were kept for all females. These females had probably laid some eggs in the field. During the remainder of the life period of these bugs, 12 females feeding exclusively on Atlas sorgo laid a total of 51 eggs, while 14 females feeding exclusively on Dwarf Yellow milo deposited 1,027 eggs, the averages being 4.3 and 73.4 eggs per female, respectively. The females feeding on Atlas plants lived an average of 8.5 days, while the longevity of females feeding on Dwarf Yellow milo plants averaged 23 days.

Complete records were kept of eggs laid by first-generation females on Dwarf Yellow milo, Blackhull kafir, Atlas sorgo, and common feterita. Ten pairs of adult bugs were tested on each of these four varieties. The 10 females on Dwarf Yellow milo laid 1,179 eggs, and their average length of life was 40 days. Eight females of the 10 feeding on Blackhull kafir deposited 219 eggs, and their average longevity was 29 days. Of the 10 females feeding on Atlas sorgo, only 4 laid eggs, a total of 9 being deposited. Fifteen days was the average length of life of the 10 females feeding on Atlas seedlings. No eggs were laid by the 10 females feeding on feterita, which indicated unsuitability for ov position in the seedling stage, although it is a susceptible variety under field conditions. Results are available which show that this variety develops considerable susceptibility as the plants become older.

Data have also been obtained which prove that chinch bugs reared on a susceptible variety can pass through their immature stages in much less time than those which are fed on a resistant variety. The average duration of the immature stages was 35.3 days when fed on

Dwarf Yellow milo and 45 days when fed on Atlas sorgo. The mortality of nymphs, after the first instar, when reared on Dwarf Yellow milo was 8% as compared with 84% when Atlas sorgo was the food plant. The average body length of adults reared on Dwarf Yellow milo was nearly 0.5 millimeter greater than that of those reared on Atlas sorgo.

Other experiments indicate that chinch bugs have the ability to to select plants of a susceptible variety for feeding in preference to those of a resistant variety when the plants of both varieties are placed adjacent to one another. Data have likewise been obtained in the laboratory which show that chinch bugs will kill plants of a susceptible variety in much less time than those of a resistant variety. The same number of bugs were confined on the different varieties tested under identical conditions in regard to age of plant, time of exposure, and, so far as known, all other conditions.—REYNOLD G. DAHMS and RALPH O. SNELLING, *U. S. Dept. of Agriculture, Lawton, Okla.*, and F. A. FENTON, *Oklahoma A. & M. College, Stillwater, Okla.*

A CONVENIENT LABEL STAKE FOR NURSERY PLATS

A METAL stake and label holder, shown in Fig. 1 designed at the United States Dry Land Station, Lawton, Okla., in 1933 has been sufficiently satisfactory to seem to merit a brief description.

The stake is made from 3/16-inch mild steel rod, cut in 2-foot lengths. An eye is turned on one end of the rod for attaching the label holder. The stake is bent just below the label holder, thereby placing the label at a convenient angle to read with the stake in a vertical position.

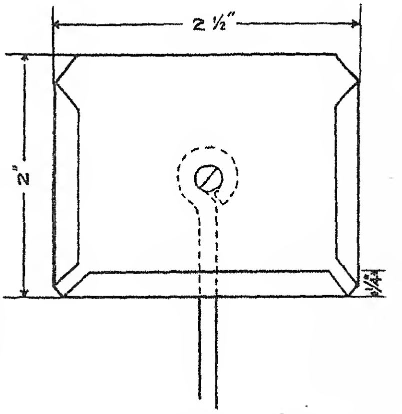

FIG. 1.—Diagram of a metal nursery stake and label holder.

The label holder is similar to that described by Swanson[1], but for attachment to a wooden stake. It is made from No. 28 gauge galvanized iron and is 2½ inches wide and 2 inches high. An ordinary manila tag, 2 3/8 by 4 3/4 inches, will make two labels for this holder. Manila tag board can be obtained in large sheets. The guides, about 3/16 to 1/4 inch in width, extend about 1 3/4 inches from the bottom of the holder. The top is only slightly crimped, which holds the label in place and permits its insertion or removal with ease. The bottom is crimped in the same manner as the guides. The holder is attached to the metal stake with a 1/2-inch flat head stove bolt, with a washer next to the stake. The head of the stove bolt is partly countersunk

[1]SWANSON, A. F. A useful holder for plat stake labels. Jour. Amer. Soc. Agron., 22 : 188–189. 1930.

in the label holder so as not to interfere with inserting or removing the label.

This stake with holder attached can be pushed into the ground when the soil is too dry and hard to permit driving a wooden stake. If a stake should be bent, it can be straightened easily. The portion of the rod that is in the soil may rust slightly but that helps hold the stake in place. The latter may be pulled up easily after a turn to break the contact with the soil. This stake will last much longer than a wooden stake, especially at Lawton, Okla., where termites cause damage, and it is lighter and less bulky. The cost of both stake and label holder is small.

The metal stake is very satisfactory for the use of permanent labels for trees, shrubs, and other perennials. For this purpose a zinc label is used instead of a manila tag. Permanent lettering may be made on the zinc with special commercial inks or with the following formula: Copper acetate (basic), 1 dram; ammonium chloride, 1 dram; lamp black, ½ dram; and water, 10 drams.—R. O. SNELLING, *Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Lawton, Okla.*

BOOK REVIEW

THE LAND, NOW AND TOMORROW

By R. G. Stapledon. London: Faber and Faber. Ltd. xvii + 336 pages, illus. 15/. 1935.

PROFESSOR Stapledon is Director of the Welsh Plant Breeding Station and of course is well known to all research workers with grasses and grass land. In this book he makes a plea for better utilization of the land and the preservation of this possession on which, he believes, the future of British civilization rests. On the basis of the best figures obtainable he believes that if the decline in arable land continues at the present rate "no more than two hundred years may see the farm lands of England reduced to one half" and in four hundred years there will be "little or no agricultural land in the proper meaning of the word in England".

Being a grass specialist, Professor Stapledon discusses the various types of grass land, pointing out how they can be made more productive and thus sustain a larger agricultural population. The costs and returns from the various proposed operations are carefully analyzed, but on a basis of refunding over a term of years. He then points out that farmers need capital to undertake such improvements, the large amount of labor that would be given employment, and appeals to the state to make the condition of agriculture its concern. The author argues, as has been argued in this country, that the state will suffer from the decline of agriculture and should assist in putting it on a prosperous basis. Contrary to what has been argued in the United States, however, he pleads for greater production.

There is much more to the book than the writer of this brief review has expressed. The book should be read by every American student of the land and of agricultural problems. (A. J. P.)

AGRONOMIC AFFAIRS

MEETING OF THE SOILS SECTION OF THE SOCIETY

ALL sub-sections of the Soils Section of the Society participated in a joint program with the American Soil Survey Association at Chicago on the afternoon of December 5, 1935. A business meeting of the Soils Section convened immediately after the close of the program.

In the absence of the Secretary, Dr. H. J. Harper, Dr. C. W. Lauritzen was asked to serve as secretary previous to the election of Dr. Clarence Dorman of Mississippi as secretary for 1936. Dr. William A. Albrecht of Missouri was elected Chairman of the Section.

A motion was passed endorsing the action of the business meeting, December 4, of soil scientists belonging to any of the three organizations (American Soil Survey Association, American Society of Agronomy, International Society of Soil Science) recommending: (1) That the A.S.S.A. and the Soils Section of the A.S.A. unite to form a single organization; and (2) that the new organization shall be called "The American Society of Soil Science".

A motion was passed stipulating that the two members who had served on the committee to formulate plans for the union of all soil scientists into one organization should serve on a committee to draft a constitution for the new organization. The two committeemen are Dr. Richard Bradfield and Professor C. F. Shaw. The proposed constitution will be published in the JOURNAL prior to the annual meeting next fall.

A motion was passed authorizing the appointment of two members to serve on a committee with two members of the A.S.S.A. (Professor Truog and Mr. Baldwin) to formulate an editorial policy for papers submitted for presentation on the program of the new Society. Chairman Albrecht appointed Professor C. E. Millar and Professor Richard Bradfield to represent the Soils Section on this committee.

It was voted to leave to the committee on constitution the decision as to whether Section VI of the new organization was to be designated as Conservation or Technology.

The following resolution presented by Dr. J. G. Hutton was adopted: That the American soil scientists recommend to Congress that there be $1,000,000 appropriated yearly for 10 years for soil survey work, this money to be allocated to those states that appropriate $10,000 per year for soil survey purposes.

During Friday, December 6, the various sub-sections conducted programs under the direction of the chairmen, as follows: Dr. H. W. Batchelor, Biology; Dr. L. B. Olmstead, Physics; and, due to the illness of Dr. R. H. Bray, Mr. G. N. Ruhnke of Ontario Agricultural College was asked to serve as Chairman of the Chemistry Sub-section in the morning, and Dr. F. C. Bauer of Illinois of the Fertility program in the afternoon.

Chairmen of the three sub-sections for 1936 were elected as follows: Soil Physics, Dr. L. D. Baver of Missouri; Soil Biology, Dr. J. K.

Wilson of New York; Soil Chemistry and Fertility, Dr. R. H. Bray of Illinois, since illness prevented his presiding over the program he had arranged this year.—CLARENCE DORMAN, *Secretary*.

NEWS ITEMS

R. H. MORRISH, extension specialist in charge of sugar beet projects at Michigan State College, has resigned to accept a position with the Soil Conservation Service at Zanesville, Ohio. His place will be taken by G. F. Wenner, who has been working on general extension projects.

DR. CARTER M. HARRISON, National Research Council Fellow, has been appointed research associate in farm crops at Michigan State College, where he will conduct pasture investigations.

STANLEY P. SWENSON has resigned from his position as Research Assistant in the Division of Agronomy and Plant Genetics, University of Minnesota, to become Associate Professor of Agronomy at the South Dakota State College.

DR. H. B. MANN, Agronomist in Soil Fertility at the North Carolina State College of Agriculture, has joined the staff of the American Potash Institute, Inc. He will serve as Assistant Manager of the Southern Territory of the Institute with headquarters in Atlanta, Ga.

DR. WILLIAM G. COLBY has been named research professor of agronomy at Massachusetts State College. Dr. Colby was formerly assistant agronomist with the Soil Conservation Service of the U. S. Dept. of Agriculture.

ERRATUM

ON page 863 in Volume 27 of this JOURNAL, in the article on "The Determination of the Forms of Inorganic Phosphorus in Soils" by R. Anderson Fisher and R. P. Thomas, in the section on "Methods of Procedure", the sentence beginning "The pH 2 solution consists of a 0.002 N sulfuric acid and 0.3% of potassium acid sulfate" should read simply, "The pH 2 solution consists of 0.3% of potassium acid sulfate." Also, on page 871 of the same article, formula 3 at the bottom of the page should read "3. pH 2 for 3 hours gives A+6B / 11+C/2."

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REGIONAL LAND USE FOR THE HARD RED WINTER WHEAT BELT[1]

R. I. THROCKMORTON[2]

IN considering a land use program for the hard red winter wheat belt it should be recognized that this agricultural region is primarily adapted to an extensive type of farming. It is a region adapted to the use of power machinery and to a type of agriculture in which the individual farmer cultivates a large acreage, has a high total production of grain in favorable years with a relatively low yield per acre and a low unit production cost. These conditions lead to a speculative type of agriculture. In a region such as this, soil and water are the most important natural resources and land use adjustments should be those that will aid in conserving these natural resources as well as assist in stabilizing the agriculture of the region.

Stabilization of production is one of the great needs of the agriculture in this region. It is essential that the wide range between extremely high total production during favorable years and the extremely low total production during unfavorable years be narrowed materially. Total crop failures on millions of acres of land occur too frequently, especially in the western portion of the region. They occur much more frequently than would be the case if a more conservative type of agriculture were practiced. A major objective of a well-developed land use program should be to reduce the agricultural hazards of the region.

The program must take into consideration the natural adaptation of the heavier soils, consisting of silt loams and silty clay loams, for the production of wheat. It should also give consideration to the climatic conditions which make this region better adapted to the production of hard red winter wheat than to most other crops.

During the early development of the hard winter wheat region little or no thought was given to land use or to crop adaptation. Land was broken from the native sod and seeded to wheat at an amazingly rapid rate. The fever of exploitation ran high and many

[1]Contribution No. 256 from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kansas. Presented as a part of a symposium on "Regional Land Use" at the annual meeting of the Society held in Chicago, Ill., December 5 and 6, 1935.

[2]Head of Department.

mal-adjustments came into existence. Land too rolling, too sandy, or located in regions too deficient in rainfall for successful wheat production was placed under cultivation. Farm units were organized in some sections too small for economical production under the type of agriculture that must be practiced considering the climatic and market conditions of the region.

The rapidity with which land was put under cultivation in the five leading hard red winter wheat states from 1900 to 1930, as given in the U. S. Census reports and Year Books of the U. S. Dept. of Agriculture, shows clearly what has happened in the region. In 1900 the total acreage under cultivation in the five states of Colorado, Kansas, Nebraska, Oklahoma, and Texas was 56,100,000. The acreage under cultivation increased to 70,000,000 in 1910, to 83,300,000 in 1920, to 88,600,000 in 1925, and to more than 97,400,000 by 1930. Much of this increase in acreage of tillable land, almost 74% or 41,300,000 acres, took place in the western part of the region, although much virgin land was broken in the eastern portion during and immediately following the World War. Texas and Oklahoma accounted for more than 24,000,000 acres of the total placed under cultivation during this period of 30 years.

Although there was an increase of almost 74% in the acreage of all crops under cultivation from 1900 to 1930, there was a much greater percentage increase in the acreage of wheat.

In these five states, 9,300,000 acres were devoted to wheat in 1900. This acreage was increased by only about 250,000 by 1910, but by 1920 it had increased to 17,850,000 acres. In other words, the acreage seeded to wheat practically doubled from 1910 to 1920. There was an increase in the area of land used for wheat of approximately a million and a half acres from 1920 to 1925. During the next five years, 1925 to 1930, there was a greater increase in the rate at which the land was placed in wheat production, especially in Kansas and Texas. By 1930 there was a total of about 24,900,000 acres used for this crop in the five states as contrasted with 9,300,000 acres in 1900. This is an increase of 15,600,000 acres of wheat in a period of 30 years and about one-half of the increase took place during the last 10 years of the period.

Throughout the entire region there should be a reduction in the total wheat acreage to aid in stabilizing production and farm income, to bring production more nearly in line with demand, and to conserve soil fertility and soil moisture. From experiences of the past and from present indications it appears that the total wheat area of the region should be reduced by approximately 5,000,000 acres or about 20%. Although this is an enormous acreage to remove from wheat production, it is believed that the total is not excessive in view of the welfare of the future agriculture of the region. The reasonableness of this recommendation is shown by the fact that several million acres of land unsuited for wheat production have been brought under cultivation and seeded to this crop.

The wide variation in soil and climatic conditions of the hard red winter wheat belt makes it impossible to adapt any land use program to the entire section. This makes it desirable to divide the

region into several sections, each of which should be considered separately because of variations in crop adaptation. The average annual precipitation for the area varies from about 35 inches in the eastern portion to approximately 15 inches in the western portion. Evaporation from a free-water surface varies from approximately 36 inches for the growing season in the eastern part to about 52 inches in the southwestern section. The altitude ranges from approximately 1,000 feet to more than 5,000 feet. The soils vary from heavy silty clay loams to sands.

For convenience of discussion the region will be divided into three sections—eastern, central, and western. Each of these will be subdivided to some extent, especially where wide variations in soil exist.

THE EASTERN SECTION

The eastern section represents that portion of the region where climatic and soil conditions are favorable for a more general type of agriculture. In this section alfalfa, sweet clover, and tame pasture grasses may be grown successfully. Straight wheat farming should not be practiced in this section, and it is here that the greatest change from wheat to other crops should be made. Within this region extensive areas of sloping, rolling, and even hilly land were broken and used for wheat production during and immediately following the World War. Much of this land has remained in wheat. Soil erosion has removed much of the surface soil on the steeper slopes and the subsoils are being exposed. The nitrogen and organic content of these soils is being reduced at a rapid rate. These steeper slopes must be returned to grass for pasture purposes or be planted to other soil-binding crops in the near future or they will become so low in fertility and water-absorbing capacity that they will be of only limited value. On the level or the gently sloping soils in this section sufficient land should be seeded to permanent and temporary pasture to meet the grazing needs of the livestock normally produced in the area. The pastures are so limited in extent on practically all farms that there is not sufficient grass to meet the needs of the livestock except during the most favorable seasons. This condition has led to over-grazing which has resulted in a decided reduction in the carrying capacity of the pastures and on many farms the pastures have been denuded of practically all native grasses.

In this eastern section a shortage of feed for livestock frequently occurs during the winter period. By removing some of the land from wheat and using it for the production of corn and sorghums in the northern portion of the area and for sorghums farther south, the feed situation would be greatly improved. As an aid in improving the fertility of the soils and in producing high-quality wheat, sweet clover should have a more permanent and more definite place in the agriculture.

THE CENTRAL SECTION

The central section represents that portion of the region which produces a high percentage of the hard red winter wheat. Wheat production is more dependable in this section than farther west.

However, failures are too frequent to permit a stable agriculture to be built on continuous wheat production. The topography of the land encourages the use of a heavy type of power equipment and extensive wheat production. A large proportion of the level and gently sloping land has been brought under cultivation and in some parts of the area the steeper slopes and rolling lands have also been broken. The more level areas are better adapted to the production of wheat than to any other crop, with the exception of the sorghums. For this reason wheat undoubtedly will and should continue to be the chief source of cash income.

The more sloping areas are not well adapted to the production of wheat or any other cultivated crop because a high percentage of the rainfall is lost through surface runoff. Erosion is also seriously injuring the soil. It is difficult to determine what use should be made of these steep slopes. It has frequently been said that they should be returned to grass, but the re-establishment of grass in a practical manner on large areas is difficult or impossible. Economical means of re-establishing the native buffalo, grama, wheat and blue stem grasses have not been devised and tame grasses adapted to the region are not available except perhaps in the more northern portions. An economical use of such lands appears impractical until grasses that are adapted to the region are developed or introduced or until more practical methods are devised for re-establishing the native grasses.

The wide range of crop adaptation on the sandy soils, on the one hand, and on the heavier types, which consist largely of silt loams and silty clay loams, on the other, makes it desirable to divide the section into two portions based on soil differences.

The heavier types of soil throughout the entire section are well adapted to the production of wheat, to the production of corn and barley in the northern portion, and to the production of the sorghums in the southern portion. Corn fails so frequently on these soils in the southern part of the section that it is desirable to replace corn with grain sorghums to a considerable extent. Throughout the entire area on the heavier soils the acreage used for the production of the sweet sorghums usually is not sufficient to meet the forage needs of the livestock. The lands have been broken so extensively that there is not sufficient pasture remaining to supply grazing for the livestock and at the same time maintain the pastures.

Since moisture is the limiting factor in crop production, a portion of the wheat should be seeded on fallow land each year. A higher percentage of the wheat land should be summer fallowed in the northern portion of the section than in the southern.

The problems may be met partially and the agriculture made more stable by decreasing the acreage used for wheat production and devoting the land taken out of wheat to the production of feed crops and to summer fallow. An increase in the acreage of grain and forage sorghums for winter feed and of Sudan grass for summer pasture would aid materially in solving the feed problem. Complete wheat failures also could be largely eliminated by growing a portion of the wheat on fallowed land. In those areas where considerable livestock is produced and where spring-seeded small grains are not adapted,

fallow is also the most practical intermediate step in changing the land from sorghums to wheat. A year of fallow may be followed successfully by two or three years of wheat after which the land may be returned to feed crops or to fallow.

That there are many farmers within this section who produce no crop other than wheat and who will no doubt continue to do so for many years to come is certain. Because of the wide fluctuations in annual and seasonal rainfall these men frequently experience a total crop failure. Under this type of agriculture at least one-fourth of the cultivated land should be removed from wheat production each year and be used for summer fallow. If such a system were practiced the total production of wheat would be reduced materially during favorable seasons when high yields are secured almost regardless of the tillage method used and total failures would be greatly reduced during unfavorable seasons. Objections have been raised to the use of summer fallow in this section because of the danger of increasing the tendency of soil erosion by wind. This is not a valid objection because wind erosion will be reduced rather than increased when fallowed fields are properly prepared and managed.

The sandy soils in this section cannot be classed as good wheat lands and the acreage of such soil devoted to this crop should be reduced. Such land taken out of wheat production should be used for the production of corn and sorghums for grain and forage and Sudan grass for pasture. These soils are more subject to erosion by wind than are the heavier types and for this reason are more difficult to manage under fallow. Because of this condition, wheat on these soils should follow wide-spaced row crops or wheat rather than a clean fallow. As soon as grass adapted to these soils is available, the more sandy areas should be returned to pasture. The longer these very sandy soils are under cultivation, the greater menace they become to the agriculture of the surrounding areas and they also become more subject to extreme injury by wind erosion.

THE WESTERN SECTION

The western section of the region consists of that portion having the lowest annual rainfall and frequent periods of extended drought. Complete crop failures are relatively common and considerable abandonment of wheat occurs in some portions of the section nearly every year. It was in this section that the greatest expansion of the wheat acreage took place between 1920 and 1930. Because of frequent crop failure, light rainfall and relatively frequent droughts resulting in great expanses of unprotected soils, soil erosion by wind occurs more frequently and more extensively in this section than in the more eastern portions of the region. The adverse climatic conditions make it difficult to plan a satisfactory land utilization program for the section.

It has been said rather frequently during the last few years that much of the land in this section should have been left in native vegetation, that much of it is submarginal, and that it should be returned to pasture. The fact remains, however, that much of the land has been broken from the sod and that there are many successful farmers in the region. Previous to the recent period of drought through which

this section has been passing, these lands were not spoken of as submarginal and with the recurrence of periods of normal rainfall this section will again be regarded as an important part of the hard red winter wheat belt. Wheat production, however, is extremely hazardous in most of the area. For this reason the individual who depends upon wheat as his only source of income should have sufficient reserves to enable him to withstand two or three consecutive years of crop failure. He must realize that there is little opportunity for stability and little or no chance for continuous profitable annual production.

Because of the adverse climatic conditions and the hazards of wheat production, a land use program for this section should provide for a greater diversification of income through a greater use of row crops, chiefly sorghums. It should also provide for soil management and tillage methods that will aid in preventing soil erosion by wind.

The wide variations in crop adaptation of the sandy lands and the heavier soils make it desirable to divide the section into two areas based upon these two groups of soils.

The heavier soils are better adapted to wheat production than are the sandy types, but even in the more favorable locations on the best soils, crop production is hazardous and low and unprofitable yields and crop failures are relatively common. Only the more level lands in this area should be used for wheat production. The sloping and rolling areas that have been broken lose a high percentage of the rainfall by surface runoff, making it difficult to store sufficient moisture in the soil to insure a crop. When the soils are not properly managed, become dry, and there is not a cover of vegetation, they are subject to destructive erosion by wind.

For the future welfare of the soils and the agriculture of this region the more sloping and rolling lands and a portion of the more level areas should be returned to grass as soon as seed of adapted varieties is available and economic means have been devised for the re-establishment of grass cover. Previous to the development of such grasses and methods, it will be necessary to depend upon annual pasture, hay, and other forage crops and to manage the soil so as to conserve as much of the rainfall as possible.

The acreage seeded to wheat annually in this section should be reduced more than one-half and the land taken out of wheat production should be used for summer fallow and for the grain and forage sorghums in the southern portion and for corn and early maturing forage sorghums farther north. The agriculture on these heavier soils can be made more dependable and more permanent by a systematic use of summer fallow. The fallow should be used not only for wheat, but also for the grain and forage sorghums. In general wheat should not be seeded on these soils except when summer fallow has been practiced. This means than one-half of the wheat land should be summer fallowed each year. A part or all of the acreage of grain and forage sorghums, including Sudan grass for pasture, should be planted on fallowed land. The objection is frequently raised in this section as well as farther east that summer fallowing increases the susceptibility of the soil to erosion by wind. Again, this objection is

without foundation because land that has been properly summer fallowed is less susceptible to erosion by wind than is most of the land that is not fallowed and has no vegetative covering because of a lack of soil moisture.

The sandy soils of this section occur primarily in the southwest portion of the hard winter wheat region. They present some serious and difficult problems in land utilization. Most of these soils should never have been broken from the native sod partly because of the nature of the soils and partly because of the climatic conditions under which they exist. They are not adapted to wheat production and as a rule should not be used for this crop, although in the past great areas have been seeded to wheat. The low growing or dwarf types of grain sorghums, the early maturing varieties of the sweet sorghums, and Sudan grass should occupy most of the acreage of the cultivated sandy soils. In some areas corn is perhaps almost as dependable as the grain sorghums. These row crops should, under most conditions, be planted in wide-spaced rows with a smaller amount of seed per acre than is commonly used. If wheat is grown it should be seeded between the wide-spaced rows. A high percentage, if not all, of these sandy soils should be returned to grass. It must be recognized, however, that methods have not been developed for seeding or otherwise re-establishing grass cover under such conditions.

These sandy soils are extremely subject to erosion by wind and the longer they are under cultivation the more susceptible they become to this injury. In some sections they have become so severely eroded by wind that they have little or no value for economic crop production. As long as such soils are without protective covering they are a constant threat to surrounding areas. The immediate problem is to establish cover of some type on these lands and then plan to re-establish a permanent type of vegetation as soon as economical methods are available.

SUMMARY

In presenting a regional land use program for the hard red winter wheat belt the following points have been considered:

1. The region is adapted to extensive farming which encourages a speculative type of agriculture.

2. The program on land use should plan to conserve the soil and water resources and aid in stabilizing the agriculture of the region.

3. The area under cultivation in the five leading hard red winter wheat states increased from 56,100,000 acres in 1900 to more than 97,400,000 acres by 1930. The area devoted to wheat increased from 9,300,000 acres in 1900 to 24,900,000 acres in 1930.

4. Much land that is too rolling, too sandy, or located in regions too deficient in rainfall for successful crop production has been placed under cultivation.

5. For the welfare of the agriculture of the region, it appears that the total wheat area should be reduced by approximately 5,000,000 acres or about 20%.

6. The land removed from wheat production should be used for soil-binding and soil-improving crops, pasture crops, and feed crops in the eastern portion of the region. In the central portion it should be used for increasing the acreage of feed crops and for summer fallow. In the western portion it should be used for a material increase in the acreage of sorghums and other row crops and for summer fallow.

7. One of the greatest needs of the region is the development or introduction of a grass or of grasses that may be used to re-establish sod on the sandy areas and on the sloping and rolling lands.

SOME PROBLEMS OF LAND USE IN THE CORN BELT[1]

P. E. Brown[2]

"'WESTWARD the course of empire takes its way' with ruined lands behind." I cannot on this occasion resist repeating this often-quoted paraphrase of an age-old line, just as it was uttered so trenchantly many years ago by that pioneer Corn Belt proponent of the theory of planning a permanent agriculture, Hopkins of Illinois. To him more than to any other single individual we can trace the beginnings of the theories and practices of soil conservation as designed to fit Corn Belt conditions.

For some years we waged an uphill battle to bring about any general recognition of the fact that "soils will wear out". It took time even to win a hearing for such a "bear story" with many Corn Belt farmers. They were still farming rich Corn Belt land and growing good crops and they simply refused to get excited about methods of soil management and the depletion of soil fertility. They were making good profits. Why worry?

But some progress was made and a few farmers here and there who were more receptive to new ideas were induced to try out the things the "college professors" were suggesting. They did this probably with their fingers crossed, and to their surprise the treatments were found to be worth while. Such tests often served as demonstrations and these, along with experiment station publications giving the results of experimental work, and much extension activity, gradually led to some interest in the land and its management.

About this time it began to be apparent to many farmers that their soils were becoming depleted in fertility. They found that their crop yields were declining. They noted that it had become increasingly difficult to grow clover and was often quite impossible. They were also painfully aware that their incomes were decreasing, and while they were inclined to attribute this to politics or to the party in power, they were forced to admit that it was partly due to lower crop yields per acre on their lands. They were obliged in many cases to plow up more land to plant to corn in order that they might grow enough to supply feed for their livestock. This often meant that the washing away of the soil became progressively greater and greater. So the depletion in fertility and the erosion losses on individual farms soon reached a point where farmers were becoming alarmed over the situation. The thought began to take shape in our minds that the problem was becoming too serious to be handled by the individual farmer and that state or national action would ne needed if we were to avoid a condition of bankrupt farmers on bankrupt land—a bankrupt agriculture.

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[1]Journal Paper No. J314 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 363. Also presented as part of a symposium on "Regional Land Use" at the annual meeting of the Society in Chicago, Ill., December 5 and 6, 1935.

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And then along came the depression. The stage was all set agriculturally for a real show and that is just the sort of a show it was. The foreign markets had disappeared and the domestic market was toppling, but the farmers went on producing more and more agricultural products as prices declined in the vain hope of selling enough in quantity to offset the low receipts. Naturally, a great surplus appeared and then there was no market at all and the situation of the farmers became desperate. In fact, the whole country was plunged into the depths of despair. There were millions unemployed and starving, literally in the midst of plenty, or at least in the midst of a great surplus of agricultural food supplies. What a curious and anomalous situation. There was no time to investigate causes nor to speculate on how it might have been avoided. The important thing was to find out what to do about it. Many suggestions were offered and some remedies were tried with little or no effect and for some time the situation looked hopeless. "Prosperity was just around the corner", but the corner seemed to keep moving further and further away. But I need not digress to discuss the measures adopted for the relief of agriculture. Suffice it to say that we have come a long way from the depths of the depression, and we began to "bog our way out" just as soon as it was recognized that a "pink pill would not cure a broken leg", and some drastic measures were taken.

Now comes the question where land use and soil conservation fit into the picture. At first thought it seems a curious tie-up. Why should conservation and land use be included in a program for farm relief? In the first place it may be pointed out that soil erosion was just being brought to public attention as a grave menace to our agricultural lands under the impassioned representations of that apostle of erosion prevention and control, Hugh H. Bennett, and some interest in the problem was appearing even in the Corn Belt where the effects were beginning to be noted. Indeed it was actually suggested in some of the early discussions of farm relief that the thing to do was to let erosion go on uncontrolled and the surplus of farm products would soon disappear and there would be an automatic control of production. But saner counsels prevailed! A wave of public sentiment spread over the country like wild-fire to stop the destruction of the agricultural lands. The general interest in erosion control became so great that it could not be overlooked in agricultural discussions.

And then, too, it may be recalled that many of the agricultural leaders had been talking about the need for a new land policy for at least 10 years before the National Conference on Land Use held in Chicago in 1931 and nationwide plans along this line began. The importance of a land use program was certainly in the minds of many people. Finally, it was becoming apparent to many farmers and others that soil depletion, reduced fertility, low yields, abandoned farms, mortgaged land, tax delinquency, and corporation ownership of farms were all reaching alarming proportions and a general decline of agriculture in the Corn Belt and in other parts of the country was seriously threatened.

Perhaps it is no wonder, therefore, that in the plans for agricultural

rehabilitation as they began to take definite form, land use and soil conservation began to appear. But it is certainly amazing the way these subjects have been taken up, developed, and put into operation. The literal adoption of both as integral parts of the recovery program has led some people to believe that they actually originated with the "New Deal", which is not true at all.

The situation today is indicated in the following quotation taken from the daily paper of this morning (November 17) which has come to my attention as I write: "Soil Conservation as a means of solving the farm problem has come, at least temporarily, to overshadow other plans of farm relief this year. . . . The acceptance of soil conservation and proper land use as an approach to the farm problem is recognition of the long-time view of agricultural needs instead of merely the emergency consideration which has been foremost in much of the arguments and agitation of the past."

It is interesting to note also in this connection that at a conference in the Corn Belt this past summer, it was agreed that "in the Corn Belt it (the adjustment) centers around the feed-grain livestock problem. The primary problem is to determine the ratio of feed to grass and other crops which will *most effectively conserve land resources* and at the same time permit as large a production of livestock and its products as will result in maximum net returns under existing and prospective demand conditions."

GOOD AND POOR LAND IN THE CORN BELT

Now we do have much good land in the Corn Belt still. In fact, from the report of the National Resources Board it appears that there is in the Corn Belt over one-half of the Grade 1 land, or 59 million acres out of a total of 101 million acres in this grade in the country as a whole. While, on the other hand, we have less than one-sixtieth of the Grade 5 land, or the poorest, or 14 million acres out of 881 million, we do have some submarginal land.

It may be mentioned, too, in this connection that according to the recent reconnaissance erosion survey of Iowa, 87% of the farm land in the state was found to be suffering from sheet and gully erosion in various degrees. The fertile topsoil is being washed away from more than half of the farm land (54%) at an annual rate which seriously endangers the productivity of the land. Similar figures would undoubtedly be obtained for other parts of the Corn Belt. This means that there will be a rapid increase in Grade 5 land throughout the Corn Belt unless a land use program is adopted which will prevent the occurrence of erosion.

We must consider, then, these two very important points in connection with the problem of land use in the Corn Belt. First, that we still have a large acreage of land which is rich and productive and which is *worth saving*, land on which there is still some topsoil remaining and some fertility to conserve. And, second, that we have some poor land, some submarginal areas which we must do something about.

SUBMARGINAL LAND USE

Taking up first the problem of these submarginal lands, it may be mentioned that they are defined as "not adapted for use for farming" which is perhaps too broad a definition. There are various other definitions and many variations in the concept of what constitutes submarginality. But whatever definition is accepted, it is apparent that there are many angles to the question of what to do with submarginal land. The purchase of such land by the government and the removal of families to other more productive areas was one suggestion. This proposal aroused much interest especially among land owners who had invested "not wisely but in too poor land". I understand that the government had an opportunity to buy up practically all of one of the western states (not California). So-called submarginal land in the Corn Belt could not compete in such a program. Our poorest land looked good to those who had just examined some of the lands just outside the Corn Belt. But we do have land in the Corn Belt which will not permit a farmer to prosper even under the most favorable price conditions. Such land might be purchased and taken out of production, of course, but there are difficulties in the way, in addition to the real problem of funds. What to do with the families is a grave question, and in general, the economic and sociological aspects of the situation are very important.

Then, too, such land might be purchased by the Forest Service and used for forest plantings and reforestation. This has been done extensively in some areas outside of the Corn Belt and to a limited extent in it. The land may be taken over for recreational purposes for state or national parks or for game preserves. This has also been done in a small way in the Corn Belt.

But there are real difficulties in all these usages, the chief one being that the poorest land in the Corn Belt is apt to be held at a higher figure than land in other states and the price factor is a serious deterrent to much help in these directions.

The agronomic solution of the problem is the seeding down of submarginal areas to permanent pasture. But the seeding down of large areas of land to permanent pasture, and especially of large proportions of the land on a farm, may mean a change in the system of farming. It may mean a change from corn-hog farming to beef cattle, dairy cattle, or sheep, for example. There are real difficulties in such a shift, some being economic and some personal or sociological. We have been told that the size of the farm is an important deterring factor to the seeding down of land to pasture and it has been recommended that some plan be devised for the consolidation of farms. But this again brings up the problem of what to do with the people who are moved off the small farms. In fact, it is almost impossible to evade the economic and sociological difficulties which arise in all such adjustments in land use.

Without going into the economic implications, however, it seems apparent that if the submarginal lands are not purchased by the government for retirement from cultivation, for forest purposes, parks, or game preserves, they should be put into permanent pastures just as far as possible. Then we must take steps to try to make that pasture

land as productive as possible. The proper management of such pastures on poor land is one of the problems which we are facing now and some practical recommendations along this line are sorely needed.

A LAND USE STUDY IN IOWA

In connection with the utilization of the good land in the Corn Belt and the planning for such use in the future as will conserve the soil and permit of a permanent agriculture, I wish to present briefly the results of a preliminary study of land use made in Iowa last year by Professors Firkins and Smith of our staff and consider some of the agronomic problems arising from that work.

The objective was to determine the acreage of the various soil types in each township in every surveyed county and to assign to each a specific rotation which would conserve fertility and prevent erosion of that type. These rotations were selected from a carefully chosen list of 12 standard rotations as shown in work sheet 1A.

WORK SHEET NO. 1A.—*Standard rotations upon which recommendations are based.*

Rotation No.	Crops
1	Corn, Corn, Small grain, Legume hay
2	Corn, Small grain, Legume hay
3	Corn, Corn, Oats, Mixed hay
4	Corn, Oats, Mixed hay, Rotation pasture
5	Corn, Corn, Small grain, Sweet clover (level Marshall-Clarion)
6	Corn, Corn, Small grain, Winter wheat, Clover
7	Permanent pasture
7x	Woodland not pasture
8	Special crops
9	Corn, Soybeans, Winter wheat, Mixed hay, Rotation pasture, Rotation pasture
10 (a) ½	Corn, Corn, Small grain, Clover
(b) ½	Corn, Small grain, Winter wheat, Mixed hay, Rotation pasture
11 (a) ½	Permanent pasture
(b) ¼	Corn, Oats, Alfalfa, Alfalfa
(c) ½	Corn, Soybeans, Oats, Clover
12 (a)	Corn, Corn, Small grain, Winter wheat, Alfalfa
(b)	Corn, Corn, Oats, Alfalfa, Alfalfa, Alfalfa

It was assumed that lime should be applied to about 10% of the acid soil area to permit of the use of desirable crop rotations which include legumes requiring basic soil conditions. It should be noted that occasionally any one of several rotations might prove entirely satisfactory for certain soils and choosing one was therefore somewhat an arbitrary matter, just as liming 10% of the land was quite arbitrary. But the rotations were very carefully selected and fitted to the various soil types as maintenance rotations for those types on the basis of a full and rather complete knowledge of the characteristics of the soil types, the topographic position, and the present use of the types.

The exact acreage of each type in all townships in surveyed counties was determined by planimeter measurements on the soil maps. Then the rotations were fitted to the types as indicated in work sheets 1 and 2.

WORK SHEET NO. 1.—*Township data on crops and soils recommendations.*

Blackhawk County Eagle Township Key No. 7–16

DATA FROM CENSUS 1930

No. of farms 109 Acres in farms 22572 Crop Land 16560 Plowable pasture 2929 Woodland pasture 249 Other pasture 1706 Woodland not pasture 22 All Others 1106 Area in corn 8470 Small grain 2067 Pasture total 5176 Pasture permanent X Hay legume 416 Hay mixed 1555 Other hay X Green manures X Woodland not pasture X Special crops 193 All other X Total hay 2062.

DATA FROM SOIL MAPS: SOURCE

Names of soil types	Grade	Area	Deduct Bldgs., etc.	Net area	Recommended rotation
Tama silt loam	1			17,009	1, 6, 9
Clyde silty clay loam	8			2,583	7, 1
Carrington loam	1			826	1, 2, 11c, 4
Waukesha silt loam	1			767	1
Meadow	10			193	7
Dodgeville silt loam, shallow phase	8			64	7
Muck	10			23	8

WORK SHEET No. 2.—*General crop and soils information on county.*
County: Blackhawk

Crop Land

1. Predominant Topography: Level to gently rolling. Cut by two rivers and their tributaries.
2. Erosivity: Slight to medium
3. a. Predominant Types: b. Productivity:
   Tama silt loam — High
   Carrington loam — High
4. a. Extent of Acidity: 85% b. Degree of Acidity: strong
5. Remarks: Large areas sandy—good for special crops
6. a. Pasture Types: Clinton, Carrington—Tama, Rolling Phase
   b. Lime? Yes c. Seeding mixture: Clover and timothy
7. a. Predominant Rotations: b. Acres: c. Kind of legume: Red clover

1	104,348	Soy beans—alfalfa—sweet clover
4	38,972	d. Kind of rotation pasture:
2	36,934	Red clover—timothy, sweet clover

PERMANENT PASTURE

1. Predominant Topography: Level to gently rolling
2. Predominant Type of Pasture: Upland
3. Approximate Acreage Woodland Pasture: 16,000

COMMENTS

There is relatively large area of waste land. The need of drainage is evident in many parts of the county. The area of bottomland is small. One of the first needs of the soils of the county is lime. Erosion occurs more extensively on Clinton and Carrington sandy loam. The terrace soils, as O'Neill, Bremer, Waukesha sandy loam and Calhoun, are in need of organic matter. Shorter rotations should be practiced.

The rating or grade number for each soil type was that assigned to it in previous work carried out in connection with the soil survey and study of the soil type characteristics. The general crop data were taken from the 1930 census. Over three-fourths of the counties in the state have been surveyed and soil maps are available for them. Where soil survey maps were not available, the areas of the different types in the unsurveyed counties were estimated from the averages of the areas in adjoining counties having similar soils.

The changes in crops as finally recommended were given in percentages by counties and then summarized by type of farming areas in the state as defined by the economists. The changes for the entire state and for the various type of farming areas are shown in the Figs. 1 and 2.

It may be noted that the average reduction in corn acreage recommended for the state was 19.4% over that in 1929 and this is almost the same as the minimum 20% reduction requirement of the AAA. This close agreement between the calculated desirable reduction in corn acreage as arrived at by the AAA and the reduction needed for a sound fertility maintenance program in the state emphasizes in a very striking way the close relationship which might exist between an emergency program and a long-time conservation plan for land use.

It may be noted also (Fig. 3) that there is close agreement between the results obtained in this study by individual soil types

CLASSIFICATION OF SOILS BY GRADES, ROTATIONS, AND CROPS

Areas in crops under recommended rotation.

Grades	Rota-tion	Net area	Corn	Small grain	Pasture		Hay			Woodland not pasture	Special crops	All other
					Rotation	Permanent	Legume	Mixed	Other			
I	I	9,478	4,720	2,370			2,368					
I	2	207	69	69			69					
I	4	206	52	52	51			51				
I	6	4,253	1,701	1,701			851					
I	9	4,252	709	709	1,416		709	709				
I	11c	206	157	52			103					
8	I	1,291	646	323			322					
8	7	1,356				1,356						
10	7	193				193						
10	8	23									23	
Totals........		21,465	7,967	5,276	1,467	1,549	4,423	760			23	
Adjusted totals												

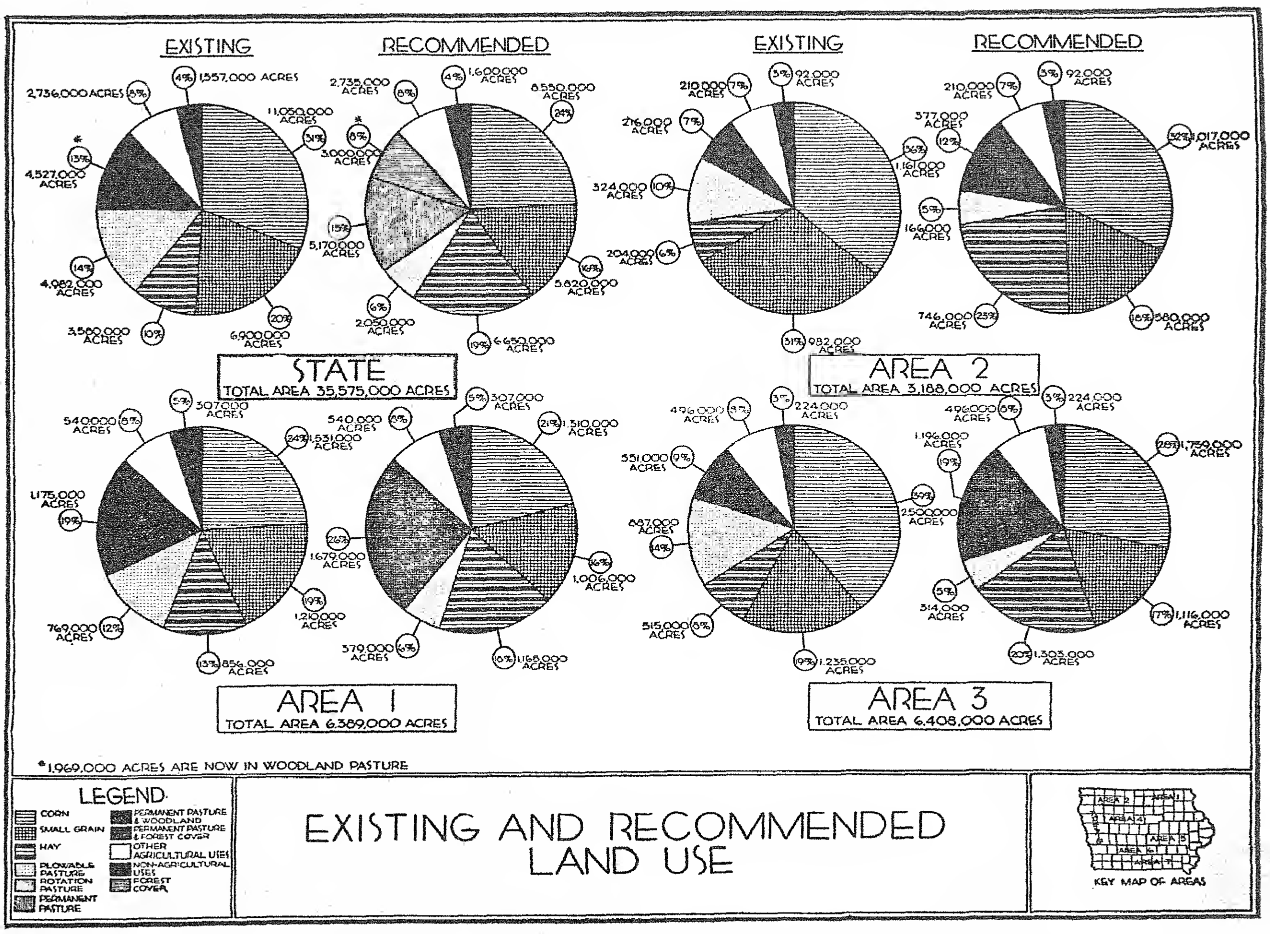
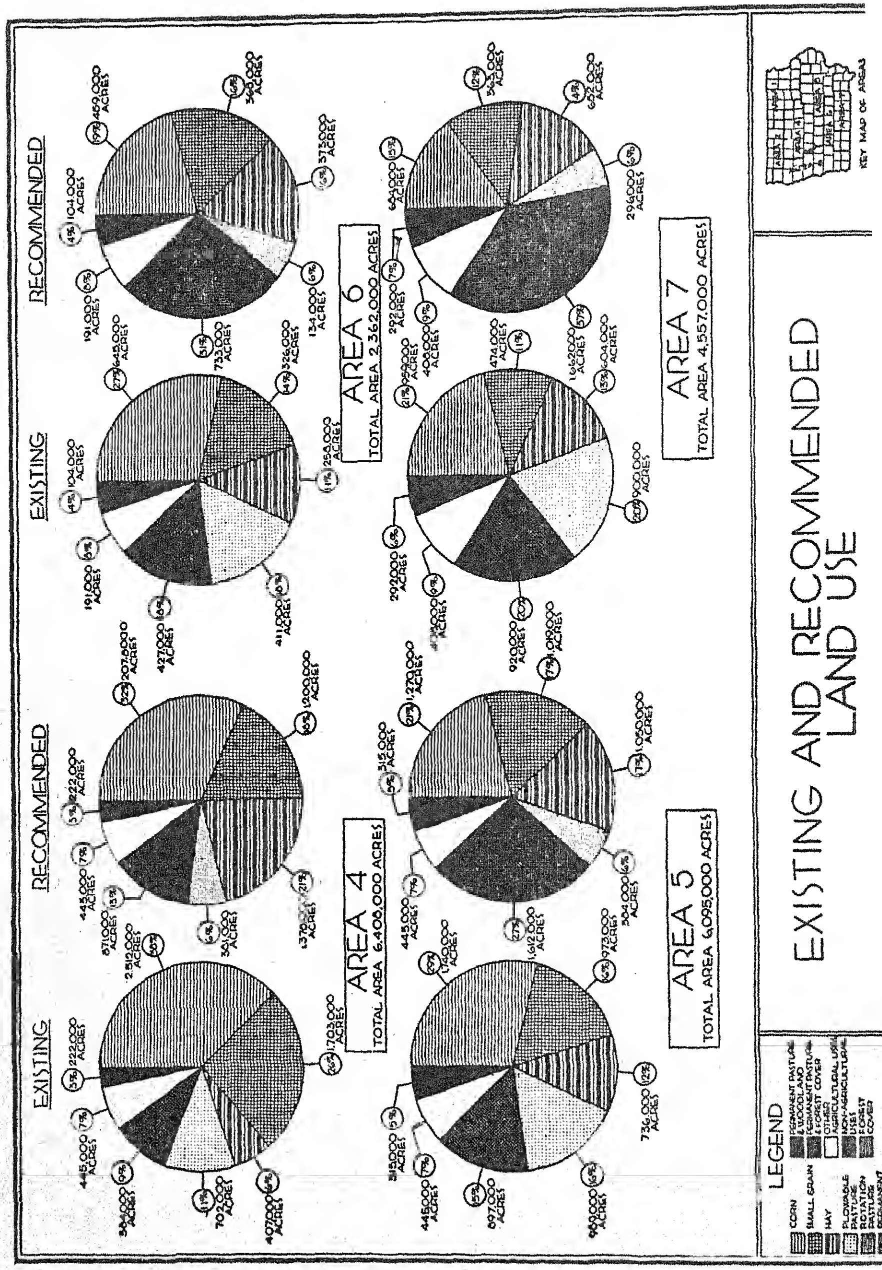


FIG. 1.


EXISTING
RECOMMENDED
AREA 4
TOTAL AREA 6,408,000 ACRES
AREA 5
TOTAL AREA 6,095,000 ACRES
AREA 6
TOTAL AREA 2,362,000 ACRES
AREA 7
TOTAL AREA 4,557,000 ACRES
EXISTING AND RECOMMENDED LAND USE
LEGEND
CORN
SMALL GRAIN
HAY
PLOWABLE PASTURE
ROTATION PASTURE
PERMANENT PASTURE
KEY MAP OF AREAS

county by county and the figures which have been used for a number of years by our extension agronomists when presenting the subject of the need for more legume growing in the state and a smaller acreage in corn in order to permit of a maintenance of the fertility of the soil.

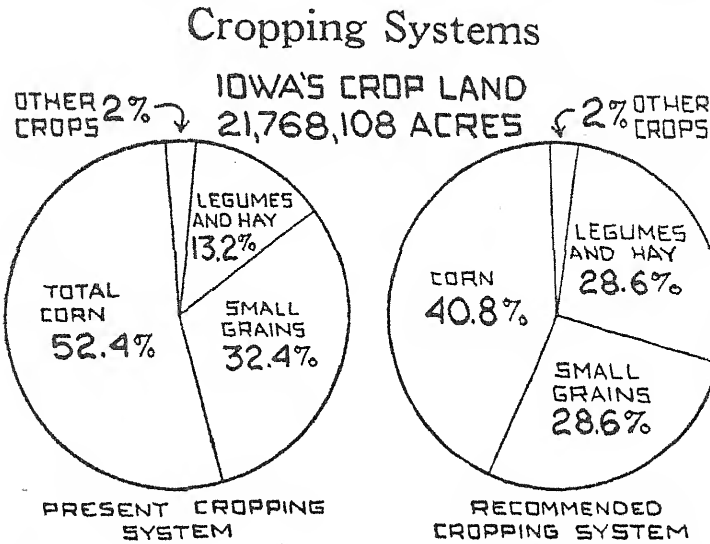


FIG. 3.—Present and desirable cropping systems in Iowa from the standpoint of soil fertility maintenance.

Then after the figures were derived for each county showing the desirable crop plan for each type, the livestock specialists took the crop production figures and transformed them into livestock systems for each county as a unit.

These recommendations from the agronomic and livestock standpoints were studied by the economists to determine the effects upon farm income, upon the systems of farming, upon feed unit production, upon the relative economic position of the various grains by counties, and finally upon a long-time adjustment program.

Now I wish to take up a consideration of some of the agronomic problems which have arisen out of this land use study and other work carried out in connection with the appraisal of land and the control of erosion. While there is no intention of minimizing the importance of the economic problems in land use, I am concentrating upon the agronomic problems, and indeed perfectly arbitrarily and with some difficulty isolating them from the economic implications.

THE SOIL SURVEY PROBLEM

The survey of the soils of an area has been quite generally agreed to be almost essential to a sound land use program. The question then arises what to do about areas which are not yet surveyed and cannot be for some years, if ever. What can be done toward land use in such cases? Perhaps reconnaissance surveys might provide the

necessary information. At least they would be the next best thing to a detailed soil survey. In some cases they might serve the purpose very well.

How to speed up the soil survey work is a grave problem in the Corn Belt as elsewhere. The pressure upon us for the data supplied by the soil survey is heavy. The problem has no answer, of course, except in increased funds for the work and a trained personnel to carry it out. There is a deplorable scarcity of men experienced in soil surveying at the present time and any increase in the amount of survey work, even if funds were provided, would be limited by the number of men available who have had the training necessary to enable them to handle the job. A few of the colleges are offering special courses along this line, as we are doing in Iowa, but we need more men than are being prepared.

Then in connection with the survey there is the problem of the scale of the maps. Shall we continue to map on the basis of 1 inch to the mile or shall we double that scale as has been suggested or go even to a still larger scale? For land classification and appraisal work can we use the same scale or should we have larger scale maps for these purposes? In farm appraisal studies larger maps have seemed desirable and even essential as a comparison of the two maps made of a sample farm appraised in this work will indicate (Figs. 4 and 5). We are now comparing the use of maps made on two different bases in some land classification studies which are under way in the complicated drift area in Iowa.

THE EROSION SURVEY PROBLEM

The problem of making slope and cover maps as a basis for erosion control operations is a serious one. Should such maps be made as a part of the soil survey? How should they be constructed? What about the methods employed in such work, the basic assumptions made, and the interpretation of the data and maps when they are compiled and drawn?

The Soil Conservation Service has been making wonderful progress in answering these questions and we have been cooperating with them in the work. We need to have some further information in these connections, however, if we are to make erosion surveys as a part of the regular soil survey work, as a part of the surveys for land appraisal and land classification work, and especially if it is to provide the most information in connection with the planning of a permanent land use program.

THE PROBLEM OF RATING SOILS

The method employed by Dr. Marbut in obtaining a rating of the soils of the country for the National Resources Board is undoubtedly the best one at present available. We rated the soils of Iowa on that basis and obtained figures which have been very useful in many ways. But there are problems here. How can we rate the soils in land areas which have not had a soil survey? How can a rating of soils be made where erosion has been active and a vastly disturbing factor? How can a potential fertility rating which is really what we have

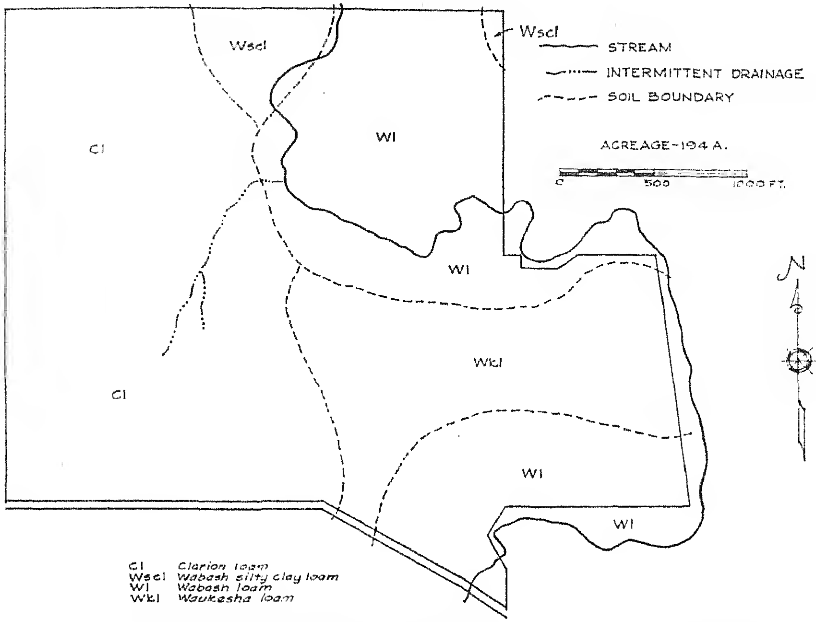


Fig. 4.—Map of farm A enlarged from county soil survey map, Iowa Agr. Exp. Sta. Bul. 326.

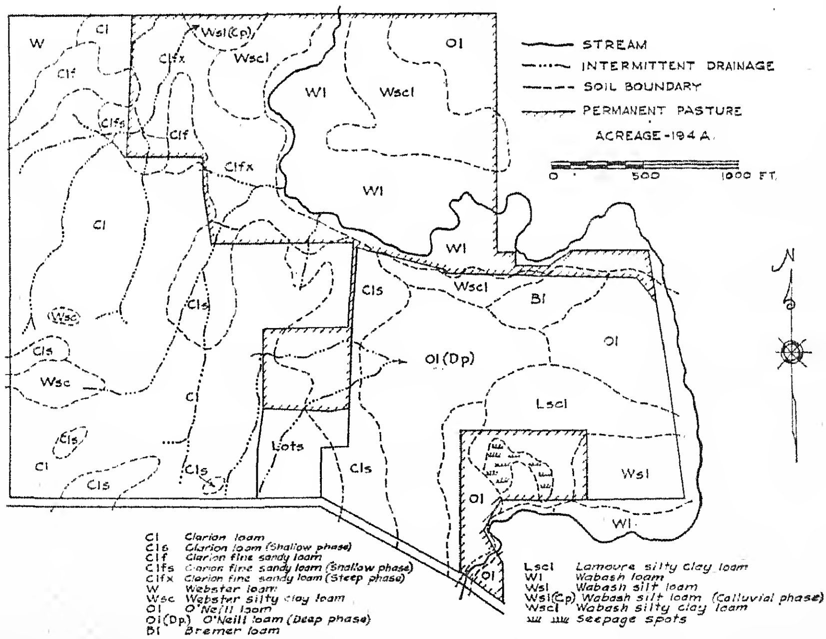


Fig. 5.—Map of farm A on the scale of 8 inches per mile, Iowa Agr. Exp. Sta. Bul. 326.

devised, or perhaps it might be called an average rating, be adapted to fit field conditions? That has been a problem in appraisal work and a flat, inelastic use of potential ratings has caused some difficulties. In the rating of farm land, for instance, Murray and Meldrum take into account the soil, the drainage, the topography, the erosion and the potential ability of the soil to produce crops. Then they make crop yield estimates with all these things in mind. Obviously, they would arrive at quite a different figure in many cases if they merely considered the potential rating of the soil. In other words, a No. 1 soil is not always in a No. 1 condition of fertility due to poor management, erosion, or for some other reason. Poor systems of soil management with consequent depletion in fertility and losses by erosion are the chief reasons for low ratings of potentially good soils. Studies along the line of fertility ratings are now under way and some method may be devised for measuring the variations in the soil types from the typical, and then by applying these variations to the potential ratings, they might be modified to fit the actual field conditions. There is no question of the value of soil ratings, but we need more information to aid us in making a proper interpretation or adaptation of them.

EROSION CONTROL AND PREVENTION PROBLEMS

The multitude of problems connected with the control and prevention of erosion is engaging the attention of the Soil Conservation Service and many other agencies and extensive demonstrational and experimental work is under way. But there are numerous problems along this line which need solution in connection with a land use program in the Corn Belt as elsewhere. I need only mention a few to indicate the importance of additional work in this field. The relative effects of various crops on erosion in different soils and the erosion-preventing efficiency of individual crops and various rotations are extremely important questions. When and how strip cropping may be efficient and the value of contour farming are significant problems. The beneficial effects of organic matter, of liming, of fertilization, upon various soils in relation to erosion prevention should be determined. How to determine soil erosivity and how to measure the soil characteristics which operate in this connection are very pressing problems in connection with the adoption of methods of erosion control in individual cases. The engineering problem of types of terraces is closely related to that of when to terrace and when it is not necessary or not even desirable. How to maintain terraces is an agronomic problem, but this will not be solved until the engineers are brought to a realization of the importance of the soil type and the soil conditions upon the construction of terraces. The best agronomic practices cannot save some terraces as has been amply demonstrated in some states and, on the other hand, terracing without proper handling of the soils and crops cannot hope to succeed.

The forestry problem of planting trees has little agronomic significance except indirectly, but it is important to know when land should be protected from erosion by reforestation and when by seeding down to permanent pasture. This problem, however, is far from a solution

as there are economic questions involved for which answers are probably a long way in the future.

I would emphasize further the fact that it is quite impossible to say what method of erosion control should be followed for each individual soil type, yet that is a question which has been frequently asked. It must be remembered that the method of soil management in the past may make all the difference in the world in the particular method of handling the land which will be required to prevent soil washing. Incidentally, we are attempting to develop at the present time some alternative suggestions for handling various soil types to control erosion on the basis of the slope, the cover, or extent of erosion which has occurred and taking into account the different methods of management which will be required because of the past mismanagement of the land.

THE PASTURE PROBLEM

When land should be seeded down to permanent pasture in order to prevent erosion and maintain fertility, is one of the very practical problems in erosion control and in land use plans. It is directly related to the efficiency of a good rotation in conserving the land, to the erosivity of the particular soil and also to the questions of the returns to be expected from pastures and of methods of management to permit of permanency and a supplying of an abundant pasturage. When will rotation pastures serve the purpose of conservation and take the place of a permanent pasture is an important practical question.

Then there are the problems of pasture establishment and handling, which must be considered. Overgrazing is certainly one of the most common causes of poor pastures as has been shown in recent studies. But how to keep a pasture in satisfactory condition under controlled grazing is largely a matter of treatment, or fertilization and reseeding. Considerable educational work is necessary in connection with pasture management to emphasize the fact that permanent pastures are crops which require just as careful attention and just as many precautions in handling as any other crop. There must be a general recognition of the value of pastures in providing feed and of the fact that fertilization of pasture may pay well, before there will be any extensive practice of the principles of proper pasture management.

There is now a changing viewpoint regarding pastures and their value and place in general farming operations and this means that they are looming larger and larger and much less ominously in the land use picture of the future. To plan to put the land into permanent pasture to prevent erosion, permit of conservation, and provide for a proper land use, no longer virtually means taking it out of consideration from the farm standpoint. It is certainly specious reasoning to say that because the income from pasture land is less than that from crop land, therefore we should not recommend the seeding down to pastures of land which is washing away rapidly and will not now produce a good crop. There is no economy in continuing to attempt to grow crops on land which is only suited for pasture.

And yet too much emphasis upon the economics of this situation has led to the idea that we should not suggest that land should go into pasture since that would change the type of farming and put the land to an extensive rather than an intensive use and because grass farming is less profitable than corn farming. The fallacy of the idea is apparent. How can it be profitable to try to grow corn on land which is so badly eroded and washed away that the yield is too low to warrant harvesting the crop? The land and its potentialities must certainly be taken into account in determining land use and we must not be over-awed nor over-persuaded by inadequate economic considerations. In many cases such as this they are quite secondary.

THE ROTATION PROBLEM

The desirability of following a good rotation system in order to maintain productivity and protect the land from erosion has been an integral part of all good soil management teachings for many years. But in the Corn Belt the profit from growing corn and the need for this crop to provide feed for the hogs has led to the practice of growing just as much corn on the land as the operator thought "it would stand". The practically continuous growing of corn in some sections, such as southwestern Iowa, for example, has gone on for years and the natural fertility of the soils was so great that good crops are often still being obtained. But mostly the "corning" process is beginning to show its effect and this is especially true since measurements of the extent of sheet erosion have been made.

While in our Iowa study of the adjustment of crops to fit the soil types, we used all knowledge available and our best judgment in selecting the rotation for maintenance, we are well aware of the fact that there are undoubtedly other rotations just as good as the ones used. No one knows what is the *best rotation* for any particular soil and set of soil conditions. So one of the great problems in land use is the selection of rotations to fit the varying soil conditions and the suggestion may be offered here that lists of optional rotations be prepared for individual soils, thus allowing modifications to fit individual conditions. The fact must be recognized that a rotation is not fixed and absolute for every soil type and given set of climatic conditions, but that there may be several arrangements of crops in sequences which would serve admirably for the same purpose.

THE PROBLEM OF ORGANIC MATTER

Directly involved in the rotation problem and indeed logically an integral part of it is the question of the maintenance of the organic matter content of the soil, for it is now recognized that even under the livestock system of farming legumes must be used as green manures if the farmer is to keep up the humus supply in his soil. No longer can it be accepted that "livestock farming will maintain soil fertility". That old idea has caused enormous damage to many agricultural lands, especially in the Corn Belt, yet we often hear the statement. But the fact that livestock farming will not maintain fertility is demonstrated on every side of us throughout the Corn Belt. In the midst of good livestock farms, good from the livestock standpoint, we find soil depletion and erosion and often a general

run-down condition of the land. And that is true in spite of the fact that more land is of course in pasture on such farms and some attempt is made to apply the manure produced to the land. There is some return of fertility to the soil in such cases, but it is *not enough*. Usually it is quite impossible to keep up the organic matter content of the soil with the farm manure produced since the amount available on an average farm will not permit of even a small addition to all the land once in the rotation. It is necessary, therefore, to practice green manuring and the problem is what to use for green manures and how fertility may be maintained by the process.

How much organic matter and nitrogen may be added by certain crops, such as sweet clover plowed under in the spring, for instance, or by hubam clover or other legumes, are important questions. Then there is the problem of the artificial inoculation of legumes, when it is necessary and how it affects the nitrogen situation. The rapidity of the disappearance of the organic matter from soils under cultivation has a definite relationship to the maintenance of the supply in the soil. The studies on carbon dioxide production in soils have given us some help in this connection, but they do not answer the question fully. Perhaps it cannot be answered except for individual seasonal soil and crop conditions. This may also be true in the case of the nitrogen added by inoculated legumes such as green manures. And then when we try to balance the nitrogen we face the question of the losses, on the one hand, and the possible additions in the precipitation and by the non-symbiotic nitrogen-fixing bacteria, on the other, and these are problems needing solution.

THE PROBLEM OF LIMING

The value of liming in connection with the maintenance of soil fertility is generally recognized in the Corn Belt. The problem in this connection recently has been the lack of funds to permit farmers to purchase and apply lime. So liming has come into the picture in connection with the Soil Conservation Service program and also as a works relief project and an activity of the CCC camps. There is also a definite program under way in the newly organized county soil conservation associations in Iowa to provide limestone at as low a cost as possible in order to speed up the liming of the land so that the best legumes may be grown and the erosion losses may be cut down or even eliminated.

Liming has been accepted as one of the basic requirements of a land use program for a permanent agriculture and, although it has required vigorous defense on sundry occasions under the attacks of the uninformed, the program for the future includes liming and will do so. The problems of how much to apply, the form to use, and effects on many crops are not yet settled. Our recommendations have been to lime the rotation, which means to meet the lime requirement of the soil. We have not held any faith in the theory of small applications of lime for general use in Iowa. It may be all right for some soils and as a temporary money-saving device, but as a general method we have no evidence yet of its superiority or its general efficiency.

We hear much about acid-tolerant crops, but while such crops do grow on certain acid soils, they have been found by experiments in many cases to produce better growth when the land is limed and the liming proves profitable. In the case of certain of the legumes there appears to be a definite relation to nodulation and nitrogen fixation and to the nitrogen content of the plants from the liming operation. This is true of soybeans, for instance. I might mention also the question of the relative effects of magnesian versus non-magnesian limestones. We have not been able to find any appreciable difference in these two materials in general in Iowa, but there are undoubtedly cases where large differences would appear. Then there is the question of the purity and fineness or amount of fine material in the limestone as applied. Our work would indicate that the requirements of the Illinois Agricultural Association are about right.

Finally, there is the question of overliming, but frankly, we are not much concerned about this, for we recommend that lime be applied only when it is needed and in amounts indicated as necessary by the tests. When this is done there is little or no danger of an overly large addition. We have had no trouble from this standpoint in Iowa. The old idea of applying limestone regularly in the rotation was erroneous and the old methods of testing sometimes gave far too large figures for the lime needs. Now with better methods of testing, we find that one application of lime may last for several rotations. In some of our experiments no further application has been found to be necessary for 16 years following the first.

THE FERTILIZER PROBLEM

There are too many individual problems under this heading to permit of any complete discussion of them. I shall merely refer to a few of the immediate and more pressing ones. In much of the Corn Belt the phosphates are still the chief fertilizers employed and much of the experimental data centers around the use of these materials. We have found, for example, that the use of phosphates on most of our soils in Iowa brings about very beneficial effects, increasing the yields and improving the quality of the crops. However, we have not yet answered the question of which particular phosphate should be employed, or of the amount of the application or the time of application. While we have found in two recent dry years that phosphates may under such conditions do more harm than good and indeed actually decrease crop yields, it is undoubtedly true, on the other hand, that if more phosphate had been used this past season, we would not be facing such a bad situation in the matter of seed corn as seems to have developed.

There is also the question of the neutralizing effect of the phosphates on the acidity of the soil. We are not particularly concerned with this point for, as has been mentioned, the liming of acid soils is considered a fundamental treatment in all our soil management systems, and the use of phosphates is recommended to follow the proper supplying of organic matter and lime when necessary. Certainly there is little possibility of avoiding the liming operation on our acid

soils by using a phosphate, and hence it does not affect us to any great extent practically.

Then there are the complete commercial fertilizers and we know far too little about them and their action under Corn Belt conditions. We have been testing certain so-called standard brands, which is merely another name for most-used brands. The results are interesting and often very significant, sometimes not. It is certainly true that with a few exceptions, we do not know what formulas to use nor how much to apply to any of our soils. We put on an arbitrary amount or an amount supplying an equivalent amount of phosphorus to that in a phosphate tested on a corresponding area. Thus we obtain a comparison under those particular conditions as to amount and brand. But we need to go much further. One of our problems in the near future is going to be that of the proper use of complete fertilizers in the Corn Belt and it is tied up directly with land use planning. There is bound to be an increasing use of these materials and we need to know what ot use and how in order to permit of the best results and to avoid disappointments and difficulties. We have learned the danger of applying fertilizers in contact with the seed and the work of the Joint Committee on Fertilizer Application of the Society has done much to pave the way for a proper use of fertilizers.

There are many other fertilizer problems which are certain to arise in our land planning, but I have concentrated upon the most important and those most discussed at present.

THE EDUCATIONAL PROBLEM

Finally, there is, of course, the grave problem of bringing farmers to an understanding not only of the importance of land use planning for soil conservation and fertility maintenance but also of the methods necessary to bring about a proper and effective land use. The great problem here is how to overcome some of the difficulties incident to a change in cropping and farming systems and in methods of soil management. As I have suggested, these are extremely important, but since they involve economic and sociological considerations, I will not discuss them except to say that they may be very largely overcome by education. Farmers are alive to the dangers of erosion, they are beginning to recognize the depletion of the fertility of their land, and they are ready to do almost anything that is necessary. But we need to educate landlords, too, and that means the general public, and we need to see to it in some way that farm leases take into account the conservation of the land and are revised on sound agronomic principles. That will take some education of a great group of people who own land and whose only concern has been to get just as much income from it as possible. Hence, in the matter of leases, it is probable that legislation will be necessary along with education. The same is true of the tax problem. Some education is needed on this subject, but it is largely a legislative problem, after the legislators are educated.

THE IOWA FARM ADJUSTMENT STUDIES

The fact that many Iowa farmers are well up on the whole situation in connection with the adjustment program and the need for a sound land use program is indicated by the conference held last summer where the proposals coming out of the land use studies which I have described were discussed. The whole problem was considered in detail for several weeks by 25 farmers from various parts of the state, and after checking up on the conditions in their own counties, they came to the conclusion that there should be a differential reduction in corn acreage, averaging about 20%, the reduction being varied (a) between groups of counties according to the reduction that would be necessary to *maintain the present level of soil fertility*, and (b) between individual farms according to crop land in corn during the base years 1932–33.

The purpose of the program, they concluded, should be to direct the use of retired corn acres into grass instead of feed grains and they proposed to do this by establishing a grass base for the county and thus arrive at a percentage of grass land for each farm. Then the contract signer to be in compliance must not only reduce the corn acreage as required but also show sufficient grass to at least equal the grass base.

THE GRASS LAND PROGRAM

The suggestion that benefit payments be made for land in grass rather than for land taken out of corn, or that the adjustment be put on a positive basis rather than on a negative basis, has been offered. This virtually amounts to paying the farmer to make adjustments in cropping systems which he has been urged to do in all our educational work out over the state for years in the interest of a permanent fertility of the soil. We have been recommending less corn and more legumes for keeping the land productive and for conserving it. We have been saying that it would pay and pay well in the long run. Now there is considerable popular belief in the idea. The grass land program when adapted to long-time planning has much to recommend it in spite of all the arguments against it which may be brought up by the economists and those outside of the Corn Belt who are not so vitally concerned with the soil and its maintenance as we are.

It took a major depression and a cataclysmic disruption of the entire economic structure of the country to bring about an appreciation of the importance of proper land use and of soil conservation and especially to bring about some action to make them a reality. But these things have happened and we are now on the spot to furnish safe and sound agronomic plans for the proper use and preservation of our one great national asset—the land.

CULTURAL METHODS OF CONTROLLING WIND EROSION[1]

L. E. Call[2]

THE erosion of the soil by wind has occurred in the Central Plains states since their first settlement. When the territory was a cattle country, before general farming was practiced, wind erosion occurred around watering places, round-up grounds, and other places where the native vegetation was destroyed by trampling and the soil left in a comparatively smooth, bare condition.

As settlers broke out the native sod and placed the land under cultivation, wind erosion became more of a problem. Serious wind erosion was usually confined to isolated fields, however, and did not cause a difficult problem to more than the few individual farmers whose fields were affected. The first extensive area in Kansas to be seriously affected by wind erosion was in Thomas County. During a period of more than 3 years an area of approximately 65,000 acres northeast of Colby in Thomas County was blown disastrously. It was feared at the time that this area might become permanently a wind-blown desert of shifting dunes of silt. Drifts of soil buried fences, railroad tracks, groves of trees, and machinery, and surrounded farm buildings. Gentle breezes filled the air with dust that sifted into houses. Stronger winds moved banks of soil so that roads readily passable in the morning might be blocked by drifts of soil by evening, making travel extremely hazardous. The few rains that fell were ineffective and no crops were grown.

This condition resulted when a period of increasing agricultural prosperity during which many acres of native grass were brought under cultivation was followed by two extremely dry years, 1910 and 1911. The total precipitation for 1910 was 6.67 inches at Colby, the lowest on record. This extremely dry year was followed with only 10.55 inches of precipitation in 1911, which was at that time the third lowest on record. There was a complete crop failure both seasons. In March 1912, a heavy snow fell. When the snow melted the soil was smooth and without the usual vegetative cover. It started to blow as soon as the surface dried. It continued to blow. With more than 20 inches of precipitation at Colby in 1912 and over 21 inches in 1913 blowing continued with increasing intensity and continued to spread over an ever-widening area. It reached the maximum intensity in the spring of 1914.

That spring a branch of the Kansas Agricultural Experiment Station was established near Colby on the edge of the district that was blowing. Steps were taken immediately to study methods of controlling blowing on the Station land. The lister was used and proved effective. An organization was then effected to protect the whole

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[2]Director.

area that was blowing through the use of listers. Some strip listing was done, but before concerted action could be taken one of the most severe dust storms in the experience of the country occurred on April 23, 1914, completely obliterating nearly all of the listing that had been done. Following this setback a more carefully organized and directed attack was made upon the problem. Mr. J. B. Kuska, Associate Agronomist, Division of Dry Land Agriculture, U. S. Dept. of Agriculture, located at the Colby Station and who assisted with the control program, reports as follows in an unpublished manuscript written in 1934 upon the methods used and the success of the undertaking:

"A program was undertaken of listing solid, or every other row, or in strips as close as possible with the listers available and planting the land to corn or other row crops. The listing was done in an east to west direction. Much of the area was so handled. For a time it looked as though even these efforts might be unsuccessful. Whether or not the efforts would have been successful of themselves will always remain a question. At about this time nature came to the rescue. A rainy period set in after the first week in May, during which it rained nine out of eleven days. These showers brought up whatever had been planted, sprouted the weed seeds which were abundant everywhere, and kept the soil from blowing long enough to give the crops and weeds a chance to become established. . . . . . . There was an abundance of moisture in the soil, and, given a start, all vegetation made rank growth. Practically all this was left over winter as protection against possible blowing the following year.

"Nature having started the healing process appeared to be reluctant to turn the job over to man at this stage. The first nine months of 1915 the precipitation was above normal every month and the total for the year was 28.99 inches, only half inch below the all time record. . . . . That fall there was an abundance of moisture for fall wheat to start and make a good growth before winter set in. The following spring there were only a few bare fields, mostly fields where the wheat was sown too late to make enough growth to cover the ground. Most fields were covered with growing wheat, heavy stubble, corn or sorghum stalks, or weeds. High winds were frequent during the spring months, and many of the fields of late wheat blew out, but no extensive areas could blow because of the vegetation. The blowing fields were strip listed or otherwise worked to check the blowing in most cases, so that the blow district was farm land again.

"Since then, almost every spring with the exception of 1919, there has been some trouble experienced with wheat blowing out in this vicinity. At no time since, even in the years when wheat winterkilled, or during the driest years has there been any extensive area of uncontrolled soil blowing. Thousands of acres of winter wheat have been destroyed, but by the timely use of the lister and other precautionary measures, the land was saved from devastation."

The conditions that gave rise to the devastating dust storms and wind erosion throughout the Central Great Plains in the spring of 1934 and the spring of 1935 were similar to the conditions that preceded the destructive wind erosion at Colby from 1912 to 1914. The 4-year period, 1931 to 1934, inclusive, had been one of deficient rainfall throughout the Central Great Plains. Some of the precipitation records typical of the region illustrate the severity of the drouth. For example, at Dodge City, where the normal precipitation for a

period of 50 years has been 20.5 inches, there was an average of 15.9 inches for these 4 years, and with a total precipitation of only 11.5 inches in 1934. Furthermore, with a normal precipitation of 11.5 inches from July 1 to March 1, the precipitation from July 1, 1934, to March 1, 1935, was but 6.5 inches. At Colby, Kansas, the total precipitation for this period was but 3.9 inches as compared with a normal of 9.8 inches.

The lack of rain during the fall of 1934 made it impossible to secure stands of winter wheat over most of the territory and where there was sufficient moisture to start the crop a lack of precipitation during the winter months resulted in insufficient moisture to maintain it. Practically all fields that had been prepared for wheat were without a protective cover of vegetation when the strong spring winds started to blow in 1935. Furthermore, due to the drouth of 1934, there was a shortage of feed for livestock. Wheat stubble, corn and sorghum stalks, and Russian thistles and other weeds were harvested for feed or grazed off so closely that little or no crop cover was left on the fields. Even native buffalo grass pastures had been so heavily overgrazed that the soil on these fields was not adequately protected.

Economic conditions combined with these favorable ecological conditions to accentuate the difficulty. Under normal economic conditions much land would be fall listed to protect it from blowing or in preparation for a spring crop. This year, however, the farmer's reresources were so exhausted following several years of crop failure that he did no more work than he thought absolutely necessary. He considered it advisable to conserve all available funds until time to plant a spring crop. Conditions were most favorable, therefore, for erosion when the wind started to blow in the spring of 1935.

This serious situation has been attributed by some to the rapid expansion in the area brought under cultivation during and immediately following the World War in response to the demand for increased food supplies. This was a major contributing factor only in some of the drier more sandy sections of the territory. In other sections this factor was important only in that it contributed to the extent of the area involved. Dust storms would have occurred and serious soil erosion would have taken place this past year if no additional land had been brought under cultivation during the war and post-war periods.

The condition that existed throughout the Central Plains territory was similar to the condition that had existed on a much smaller scale in the Colby territory 20 years earlier. With the experience at Colby as a guide an effort was made to perfect an organization in central and western Kansas where wind erosion was occurring and to take steps to stop it. District meetings were held in the affected territory attended by county agents, county drouth committeemen, and county commissioners to discuss the problem, consider methods that might be used and develop plans for making these methods effective. As a result a detailed survey of the condition of the land in each county was undertaken to determine the exact acreage that was eroding and in need of attention. The national Relief Administration

was asked to appropriate funds with which farmers might purchase fuel oil for tractors or feed for horses used in the work. An original allotment of $250,000 was made in Kansas for this purpose, which was later increased to about $328,000. This grant was made through allotments to counties based upon need as determined by the county survey and was distributed upon order from county poor commissioners to farmers who had been assigned areas to work and who had agreed to list or otherwise work the land in an approved manner to control blowing.

The survey showed that serious blowing was occurring in 47 of the 105 counties of Kansas, all located in the western and central parts of the state, and that the cultivated area in these counties exceeded 12 million acres of which over 8 million were in condition to erode from wind. This area in Kansas constituted less than half of the area comprising the so-called "dust bowl" which included parts of Oklahoma, Texas, New Mexico, Colorado, and Nebraska, as well as Kansas. Funds were granted from the Kansas Emergency Relief Corporation to farmers of the state to work 3,287,700 acres to control blowing. A report from county agents in those counties to which grants were made showed that at the close of the season 3,360,245 acres had been cultivated. The following report from Carl C. Conger, County Agent of Kearny County, is typical of these reports.

Mr. Conger says, "On April 2, 1935, Kearny County was allocated gas and oil or feed for horses for the cultivation of 80,000 acres. This was about 40 per cent of the amount apparently needed. Additional allocations of 14,000 acres were granted this county on May 22, 1935. Farmers found the task of listing their land very difficult. Even though gas and oil for doing the work were made available, in the majority of cases the equipment to do the work was either not available or was not in condition to be used for such strenuous tasks. The frequency of the dust storms and the lack of funds prevented the farmers from making necessary repairs on their equipment. About one fourth of the area that was blowing was cultivated during the dust storms. Following the spring rains, however, a large part of the remaining land was cultivated immediately. A survey during June indicated that of those who had received allocations for soil blowing control, 94 per cent had their land under control."

The efforts of the farmers to control blowing were aided this season by rainfall somewhat above that of the previous 4 years. This increased rainfall, together with various methods of cultivation that have been used to work the soil, have permitted weeds to start and crops to be planted which have re-established a cover of vegetation over much of the area in Kansas that was blowing last spring. Whereas it was estimated that 8 million acres were in condition to blow in March, 1935, a survey of the situation made the first of November showed this area to have been reduced to about 830,000 acres. Conditions in most of the other Central Plains states have improved also.

It should not be assumed from this statement that all danger of serious soil erosion by wind is past. There are areas remaining in Kansas that probably will require attention if blowing is to be avoided

next spring and conditions are also reported to be less satisfactory in some other states than in Kansas.

In the future, soil erosion by wind may be expected to become a serious problem whenever climatic conditions re-occur similar to the conditions that prevailed in Thomas County, Kansas, from 1911 to 1915 and throughout the Central Great Plains from 1931 to 1935. While conditions undoubtedly will re-occur which will require intelligent cooperative management of the land to control wind erosion, there is ample evidence available from the experience of the past to provide assurance that wind erosion may be controlled and that it should not be a major factor restricting the agriculture of this territory. Exception to this general statement should be made for certain comparatively small areas of sandy soil and perhaps portions of the more arid sections of the area that are now under cultivation. These areas should be taken out of cultivation and returned to grass or re-vegetated with some other crop cover.

To assist in understanding the cultural methods that should be practiced to control wind erosion, it may be desirable to describe in some detail the action of wind upon the soil. Prerequisite to any soil blowing is the presence of dry, partially deflocculated soil particles on the surface of a soil that is unprotected by vegetative cover. Under such conditions a strong wind will move the soil particles. At first only a few particles may be moved, but these particles sliding over the surface of the soil gradually disintegrate the soil granules producing an increasing number of soil particles of a proper size to be moved by the wind. While at first blowing is confined to a comparatively thin surface layer, the amount of soil that is moved gradually increases as blowing continues. Soil material that has blown remains in condition to be moved easily even under the impulse of moderate wind, thus the longer a soil is allowed to blow unchecked the more difficult it becomes to check it.

A small area of soil that starts to blow if unchecked constantly increases in size, involves a greater depth of soil and an enlarged area until it becomes a serious menace to all adjoining fields. Many fields protected with a vegetative cover sufficient to prevent the movement of the soil on the field itself may be started eroding by the encroachment of blowing soil from surrounding fields. When conditions favorable for blowing are long continued this encroachment of blowing soil may involve several farms, whole townships, or even counties where the areas consist largely of cultivated land. Under these conditions, which were common in the spring of 1935, control ceases to be an individual problem and becomes the concern of entire communities or even the county, the state, or the nation. The longer control measures are delayed, the more vigorous they must be and the greater the danger of permanent injury to the land. Control measures should be applied whenever possible before soil blowing actually starts. After blowing has developed over a large area, no amount of effort can stop it for more than a temporary period. The object of cultivation when blowing starts is to hold the soil in place until rains fall and vegetation starts. A vegetative cover is the only ultimate preventive of wind erosion.

While almost any soil will blow if in proper condition, the greatest difficulty of control is experienced with sandy types. The particles of a sandy soil exist as individuals or break down easily from a granulated state into individual particles of the size easily moved by wind. Sandy soil also contains less cementing material that tends to hold the particles in place or binds them together. The more rounded shape of the sand particles may cause them to move easier under the action of the wind and their greater weight may result in greater abrasive action. Because of the ease with which sandy soils erode by wind, it is exceedingly difficult after blowing starts to control it by cultivation. The lighter types of sandy soil should not be brought under cultivation under semi-arid conditions and such soils that are in cultivation should, under most circumstances, be re-vegetated. Sandy soils of a somewhat heavier character may be cultivated successfully if handled in such a manner as to keep them covered with vegetation or crop residue during the seasons of the year when blowing occurs.

The soil conditions most favorable for blowing are a smooth, finely pulverized surface free from a growing crop, weeds, or crop residue. A soil in the best condition to resist blowing is one that is covered with growing vegetation, weeds, or crop residue, or if without vegetative cover, one that is rough and cloddy.

In the Central Great Plains the cultural methods that should be employed to control blowing may be classified in three categories as follows: (1) the cultural methods used during the summer and fall tillage period prior to the winter and spring months when strong winds usually occur, (2) cultural methods used on land that is in condition to blow but has not actually started to erode, and (3) cultural methods that may be employed to stop soil blowing after it has started.

Summer-fallowed land is an example of the type of land that usually requires cultural treatment of the kind falling under the first category. The soil-blowing hazard on summer-fallowed land may be reduced by doing no more tillage work than is absolutely essential to control weed growth, to cultivate if possible only when the ground is moist, and to use types of tillage tools that do not pulverize the soil. Such tools as as the spike-tooth harrow, tandum disk, and under most conditions the "one-way" should not be used since they pulverize and level the ground and leave it in condition favorable for blowing. Instead of using implements of this character it is desirable to use clod-raising or furrow-making tools that leave the surface of the soil cloddy and rough and at the same time destroy weeds. The most satisfactory tillage tools of this character are the rod weeder and shovel cultivators of all types, such as the spring tooth harrow and "duckfoot" or field cultivator.

Land tilled with these implements will be left in as good condition to resist blowing as is practicable when a complete summer fallow system is followed. When summer-fallowed land is carried over for a spring crop, it usually falls into the second category of the above classification, that is land in condition to blow. In addition to fallow, any other land upon which no crop is grown through failure to secure

a stand would fall in this classification. Other land of this character is fall-plowed ground, especially if the ground did not turn up in lumps, or if freezing and thawing during winter slakes down the clods. Corn and sorghum stubble from which the stalks are cut sufficiently high will usually protect the soil from blowing. Land left over winter in grain stubble or with a cover of weeds will not blow and winter wheat that makes a good fall growth usually protects the soil successfully.

Any land in the Central Great Plains that is not protected by a cover of vegetation will blow in the spring if winter conditions have been such that the surface soil granules are broken down by freezing and thawing during winter and if the spring is dry and windy, as is usual in this territory. This applies to corn and sorghum land from which the crop has been harvested, wheat fields unprotected by green growth or stubble, fall-plowed land, and other unprotected land of this character. Such land should be worked in the early spring to protect it. It may be worked with a spring tooth or "duckfoot" cultivator or with any other tillage tool that will roughen the surface of the soil. When a field of wheat has survived the winter but has not made sufficient growth to protect the soil the field may be cultivated with a "duckfoot" type cultivator with the "duckfoot" shovels replaced with the ordinary cultivator type shovel. If these shovels are placed 24 to 36 inches apart they will not destroy a large percentage of the wheat plants and the soil will be roughened sufficiently to protect the field against erosion under ordinary conditions. Under extreme conditions the lister must be used.

When land reaches the condition described in the third classification and erosion of the soil has started, prompt and effective cultural methods must be used to stop it. It is more difficult to stop soil blowing after it has started than to prevent it before it actually occurs. When the soil has started to blow one of two things must be done to stop it, either some protective covering must be applied to the soil or some sort of obstruction erected to check and lift the wind current above the surface soil. Except on small exposed hill tops, where erosion frequently starts and which may be protected by applications of straw, coarse manure, or some other kind of organic matter, the first method is impractical.

The second method may be successfully employed by using the soil to erect the barriers. This may be accomplished by using any tillage implement that roughens the surface and leaves it furrowed. The clods that are brought to the surface and the furrows form the windbreaks that check the force of the wind and catch and hold the drifting soil. The greater the capacity of the furrows for holding the drifting soil, the more effective the method. Thus, the more cloddy and furrowed its surface, the more permanent the results. Any shovel-type implement may prove successful if the ground is moist and drifting has not progressed far, but under extreme conditions the lister is the most effective tool to use, since the furrows left by the lister are deep and have the maximum capacity for holding drifting soil.

Under extremely dry conditions when cloddy soil cannot be brought

to the surface with a lister, the chisel cultivator may sometimes be used effectively on heavy soils.

Another implement that has been used successfully to roughen dry hard ground is the so-called "wide-spaced one-way". This implement is made by removing all but every fourth or fifth disk on an ordinary one-way disk. This implement has not only proved effective when used on hard ground but has been economical to operate. It may be used on land too hard and dry to work with a lister.

When soil and climatic conditions are favorable for wind erosion, all cultural methods must be considered as temporary. Cultivation cannot stop soil blowing permanently, but proper methods of tillage can delay destructive action of the wind for long periods of time. Severe drouth is always associated with conditions favorable for soil blowing and if drouth conditions prevail a sufficient length of time they will overcome any plan of cultural treatment that may be devised to protect the soil. Tillage must be considered therefore as a temporary method to hold the soil until rain falls. Rain will supply the moisture necessary for vegetation to start. A cover of vegetation is absolutely essential if the soil is to be removed from a potentially dangerous condition from the standpoint of wind erosion.

Rain alone, falling on land that has been blowing, will not afford the condition necessary for vegetation to start unless followed by a period of several weeks with low wind movement. The surface soil of a field that has blown will be in condition to blow again as soon as it becomes dry. The movement of the soil will destroy any small plants that start following the rain. It is necessary therefore to cultivate the soil after a rain to break up the smooth surface in order that soil movement will be stopped long enough to enable plant growth to start. After growing vegetation reaches a height sufficient to protect the surface soil the danger of wind erosion is passed as long as the cover of vegetation remains on the field.

The following rules if adhered to should prevent disastrous wind erosion in the Central Great Plains:

1. Keep the soil covered with growing vegetation or crop residue as much of the time as possible, consistent with good soil and crop management.

2. Avoid as far as possible working the soil when it is dry.

3. Take precautionary cultural measures to protect the soil against wind erosion before it occurs and if blowing starts take prompt action to stop it.

4. Restrict cultivation for the control of wind erosion to the amount needed to obtain the necessary control.

5. Use implements for cultivation of a type that leave the surface soil rough and ridged rather than smooth and level.

6. Take advantage of any rains that fall to cultivate the soil in a manner to hold it from blowing until a growth of vegetation starts to protect the soil.

7. Re-establish permanent vegetation on areas of soil so sandy, so arid, or so impervious to water that the control of wind erosion is extremely difficult. Such areas constitute but a small portion of the cultivated land in the Central Great Plains.

Where precautionary measures such as these have been taken, destructive wind erosion has been prevented throughout most of the Central Great Plains. There is no reason to expect that wind erosion will not be controlled in this region unless climatic conditions occur that are much less favorable for the growth of vegetation than those that have prevailed during the past 50 years. The best information available would lead to the conclusion that while periods of serious wind erosion will occur in the future during times of drouth, such periods will not lead to the destruction of the soil or become a major factor that will preclude the utilization of this area for successful crop production.

THE EFFECTS OF 12-YEAR RESIDUES OF LIME AND MAGNESIA UPON THE OUTGO OF SUBSEQUENT ADDITIONS OF POTASH[1]

W. H. MacIntire, W. M. Shaw, J. B. Young, and B. Robinson[2]

THE literature relating to calcium-potassium relationships in soil systems is extensive. The subject has been attacked from several angles. When unlimed soil is agitated in water and in a neutral solution of a calcium salt, the filtrate from the latter generally shows the higher content of potassium. From this it has been deduced that incorporations of liming materials will result in a liberation of soil potassium. On the other hand, the potassium content of the rainwater leachings from an acid soil will be greater than the potassium content of the leachings from the same soil limed. As a corollary, the potassium content of the ash of a plant grown on an acid soil will exceed the potassium content of the ash of the same plant grown on that soil after full-depth liming. The two latter methods of attack furnished data that warrant the conclusion that lime does not effect a liberation of soil potash.

The literature on the subject has been presented in several previous publications from the Tennessee Experiment Station, all of which were cited in the last contribution on the subject in 1930 (4).[3] Since that time additional contributions have been made by Jenny and Shade (1), Lamb (2), Peech and Bradfield (7), Sewell and Latshaw (8), and Snyder (10), and in a joint study from the Virginia and Tennessee Experiment Stations (6).

In the several contributions from the Tenessee Station the influence of calcic and magnesic additions upon the solubility of soil potash has been measured by the outgo of potassium from native supplies and from simultaneous incorporations of potash and liming materials. The present contribution deals with the effects induced by 12-year residues of calcic and magnesic materials upon the fate of the potassium supplied by six subsequent annual additions of potassium sulfate, as measured by the content of rainwater leachings from outdoor lysimeters.

EXPERIMENTAL

At the end of a 12-year period after single full-depth incorporations of the several liming materials, during which time a detailed record of outgo of Ca, Mg, K, and SO_4 was obtained, annual applications of potassium sulfate solutions were made uniformly to the surface of the soils in 1/20,000th-acre lysimeters, at the constant rate of 270 pounds of K_2SO_4 (200 pounds K_2O, 166 pounds K) per 2,000,000 pounds of soil. The soil was not disturbed during the 12-year period subsequent to the incorporation of the liming materials, nor during the succeed-

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[3]Figures in parenthesis refer to "Literature Cited", p. 214.

ing 6-year period. The soil was a brown clay loam of a slightly sandy phase and of moderate fertility. It contained 0.93% total K and 0.009% exchangeable K, as determined by extraction with boiling N/1 ammonium chloride (9), and showing a hydrogen electrode pH value of 6.27.

The initial and single liming treatments were divided into four series. In one series of six units, the unsupplemented additions of limestone, dolomite, burnt lime, and magnesia were at the equivalent rate of 1 ton of CaO per 2,000,000 pounds of soil and the oxides of calcium and magnesium were also used at the rate of 3,750 pounds CaO≈. In the other three series of five units each, sulfur was added in one of the three forms of ferrous sulfate, pyrite, and flowers of sulfur at the constant rate of 1,000 pounds of S. The lime and equivalent MgO supplements in these three series were at the two rates of 3,750 pounds and 32 tons CaO-equivalence, respectively. Used jointly with sulfur, the 3,750-pound additions represented a 1-ton equivalent rate of CaO, plus the immediate and also the potential acidity of the sulfureous materials. All of the additions of liming materials and of sulfur were mixed throughout the soil at the beginning of the experiment in August, 1917. The first of the surface additions of the dissolved K_2SO_4 was made in August, 1929, with repetitions each year thereafter.

OUTGO OF K SUBSEQUENT TO ADDITIONS OF K_2SO_4

In considering the effects of the residues of the several liming materials upon the fate of added potassium, it should be noted that each and every form and rate of lime and magnesia had caused a decrease in the outgo of K derived from the natural supplies of potassium during the 12-year period that preceded the 6-year period of the present experiment. In those control units where the three forms of sulfur were used without liming supplements, the outgo of K was slightly greater than the outgo from the untreated soil. The sulfur additions were equivalent to $CaSO_4$ at the rate of 4,250 pounds per 2,000,000 pounds of soil, but the enhancements in K outgo were but a mere fraction of the exchange equivalent of that amount.

The outgo of K from each treatment and the concentrations of the K in the leachings for each annual period, 1929–1935, inclusive, are shown in Table 1. The averaged leachings of K, as averages for the several rates of liming materials and the sulfur supplements for the first 12-year period and for the last 6-year period, are given in Figs. 1 and 2, respectively.

There occurred an immediate increase in the outgo of K from each of the unlimed group controls. This acceleration in K outgo from the units that had been rendered more acid than the untreated soil by the additions of the sulfureous materials was distinctly greater than that shown by the soil that received only K_2SO_4. The decided increase in K outgo from the additions of K_2SO_4 to the unlimed control soil did not appear until the third year. A reverse effect was noted for the calcium and magnesium residues in 16 of the 18 limed units during the first two years. During the third annual period the outgo of K from each of the 18 limed units was decidedly greater than the amounts of K leached during previous years, but the repressive effect of the residues of CaO and of MgO were marked in the case of 14 of the 17 units, exclusive of the 3 units that received MgO at the 32-ton rate. A marked enhancement in K outgo from

TABLE 1.—*Outgo of K from a clay loam treated with calcic and magnesic materials alone and with three forms of sulfur as measured by lysimeter annual leachings during a 6-year period subsequent to additions of 200 pounds of K_2O per acre* per annum.*

No.	Treatment	K, lbs. per acre* per annum								Concentration of leachates, p.p.m.						Concentration of K in leachings p.p.m.	
		1929–30	1930–31	1931–32	1932–33	1933–34	1934–35	Total	Variation	1929–30	1930–31	1931–32	1932–33	1933–34	1934–35	Average	Variation from control
50	None	16.6	9.0	50.6	96.7	90.0	163.9	426.8	—	3.33	2.40	8.40	13.50	18.80	25.80	12.90	—
51	Limestone	16.2	10.1	51.0	83.7	92.3	147.1	400.4	—26.4	3.19	2.48	8.00	11.00	17.60	21.40	11.37	—1.53
52	Dolomite	16.7	13.3	40.7	64.5	85.3	144.3	364.8	—62.0	3.29	3.28	6.30	8.50	16.40	21.40	10.38	—2.52
53	CaO, 1 ton	15.3	7.1	40.0	64.0	87.1	120.2	333.7	—93.1	3.05	1.88	6.40	8.30	15.60	17.60	9.54	—3.36
54	CaO, 1 7/8 tons	13.8	4.0	21.2	59.9	74.7	111.9	285.5	—141.3	2.77	1.13	3.50	8.40	15.20	17.20	8.63	—4.27
55	MgO, 1 ton≈	14.5	8.4	39.1	66.9	77.5	121.3	327.7	— 99.1	2.86	2.28	6.30	9.20	15.20	18.00	9.62	—3.28
56	MgO, 1 7/8 ton≈	5.8	2.3	22.3	56.0	71.5	95.9	253.8	—173.0	1.14	0.63	3.60	7.60	14.00	14.20	7.43	—5.47
57	$FeSO_4$ alone	25.1	21.4	95.1	131.8	103.9	155.9	533.2	+106.4	5.12	6.25	16.70	18.50	22.40	24.80	16.62	+3.72
58	$FeSO_4$+1 ton CaO	9.2	3.3	29.9	74.7	98.7	127.8	343.6	— 83.2	1.88	0.95	5.00	10.40	19.60	20.00	10.43	—2.47
59	$FeSO_4$+1 ton MgO	7.3	2.8	28.9	55.9	80.9	130.5	306.3	—120.5	1.53	0.83	5.00	8.00	15.60	20.40	9.41	—3.49
60	$FeSO_4$+32 tons CaO	13.7	6.1	24.4	59.0	69.9	118.9	292.0	—134.8	2.91	1.88	4.30	9.00	15.20	20.40	9.54	—3.36
61	$FeSO_4$+32 tons MgO	15.6	9.0	90.0	158.0	127.7	176.8	577.1	+150.3	3.74	3.53	17.20	25.20	31.20	35.00	21.08	+8.18
62	Pyrite alone	20.6	21.5	86.5	117.3	93.9	165.8	505.6	+ 78.8	4.28	6.55	15.10	19.80	24.80	26.80	17.02	+4.12
63	Pyrite+1 ton CaO	10.6	2.2	20.6	56.8	71.6	130.9	292.7	—134.1	2.21	0.63	3.40	8.80	14.80	20.80	9.18	—3.72
64	Pyrite+1 ton MgO	8.6	4.5	23.7	51.2	79.0	137.1	304.1	—122.7	1.76	1.25	3.80	7.00	15.60	20.00	8.95	—3.95
65	Pyrite+32 tons CaO	11.7	4.5	7.5	45.6	69.8	115.2	254.3	—172.5	2.71	1.53	1.40	7.00	15.60	20.40	8.70	—4.20
66	Pyrite+32 tons MgO	7.6	9.0	75.7	123.7	144.4	171.1	531.5	+104.7	1.78	3.38	14.70	19.80	34.80	33.00	19.24	+6.34
67	Elemental S alone	20.3	14.7	83.8	106.6	102.7	140.5	468.6	+ 41.8	4.24	4.30	14.90	14.80	22.40	22.20	14.67	+1.77
68	Elemental S+1 ton CaO	11.3	1.5	25.8	57.4	72.5	122.9	291.4	—135.4	2.39	0.45	4.30	8.00	15.20	19.60	9.02	—3.88
69	Elemental S+1 ton MgO	9.3	1.7	18.2	40.5	71.9	132.6	274.2	—152.6	1.98	0.50	3.00	5.60	14.80	21.20	8.41	—4.49
70	Elemental S+32 tons CaO	9.0	4.2	11.4	51.1	61.0	106.3	243.0	—183.8	2.13	1.33	2.10	7.70	14.00	18.20	8.23	—4.67
71	Elemental S+32 tons MgO	6.9	5.1	72.8	138.3	133.8	161.8	518.7	+ 91.9	1.67	1.90	14.20	22.60	33.20	31.00	19.02	+6.12
	Rainfall, inches	46.0	42.5	51.8	62.0	49.0	57.5	308.8									

*2,000,000 pounds of soil.

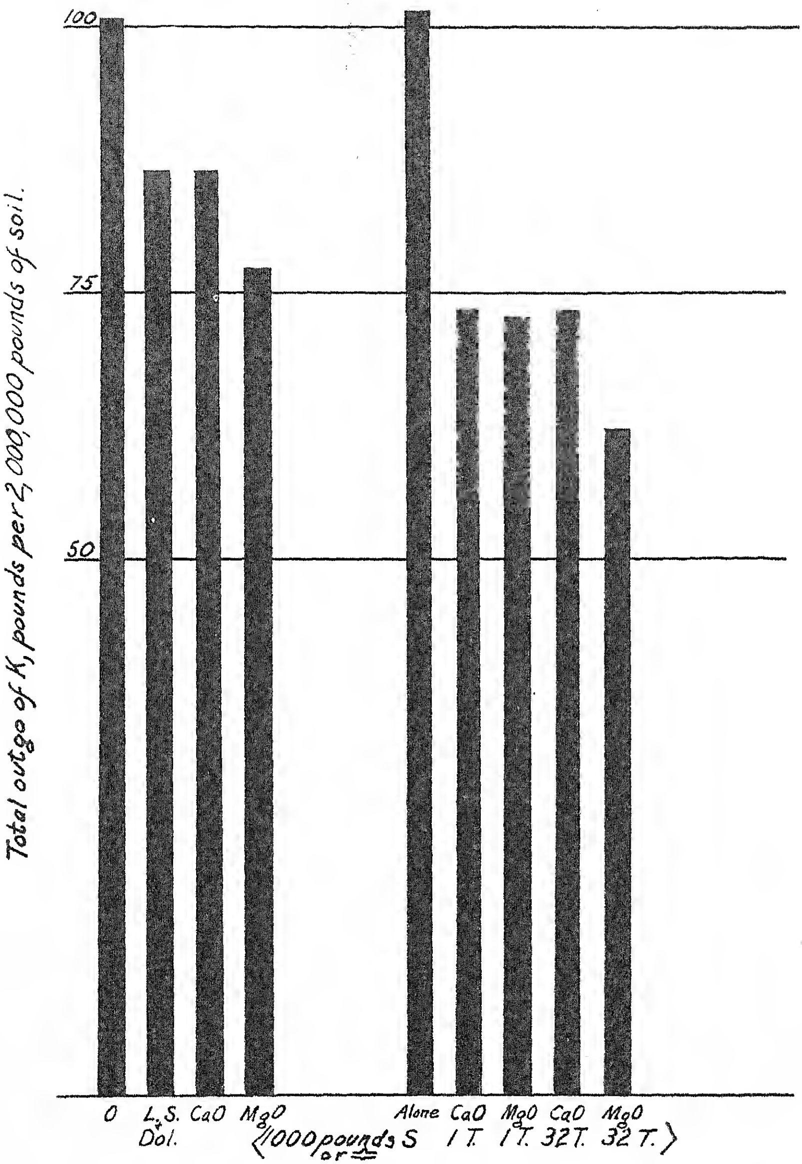

FIG. 1.—Influence of additions of calcic and magnesic materials, alone and with sulfur, upon solubility of native supplies of soil potassium as measured by outgo of K from a brown clay loam during a 12-year period. Averages for limestone-dolomite at the 1-ton CaO-equivalent rate; both CaO and MgO at 1-ton and 1⅞-ton rate; CaO at 1⅞-ton rate with supplements of $FeSO_4$, pyrite, and sulfur at the rate of 1,000 pounds S, and the same for 1⅞-ton CaO-equivalence of MgO; CaO and also MgO at the 32-ton CaO-equivalent rate with the three sulfur supplements.

all units was registered during the third year, and excepting the delayed effect for the 32-ton CaO treatments, each outgo for the third year was in excess of the corresponding total for the first 2 years. Consistently, however, the residues from all calcic treatments in-

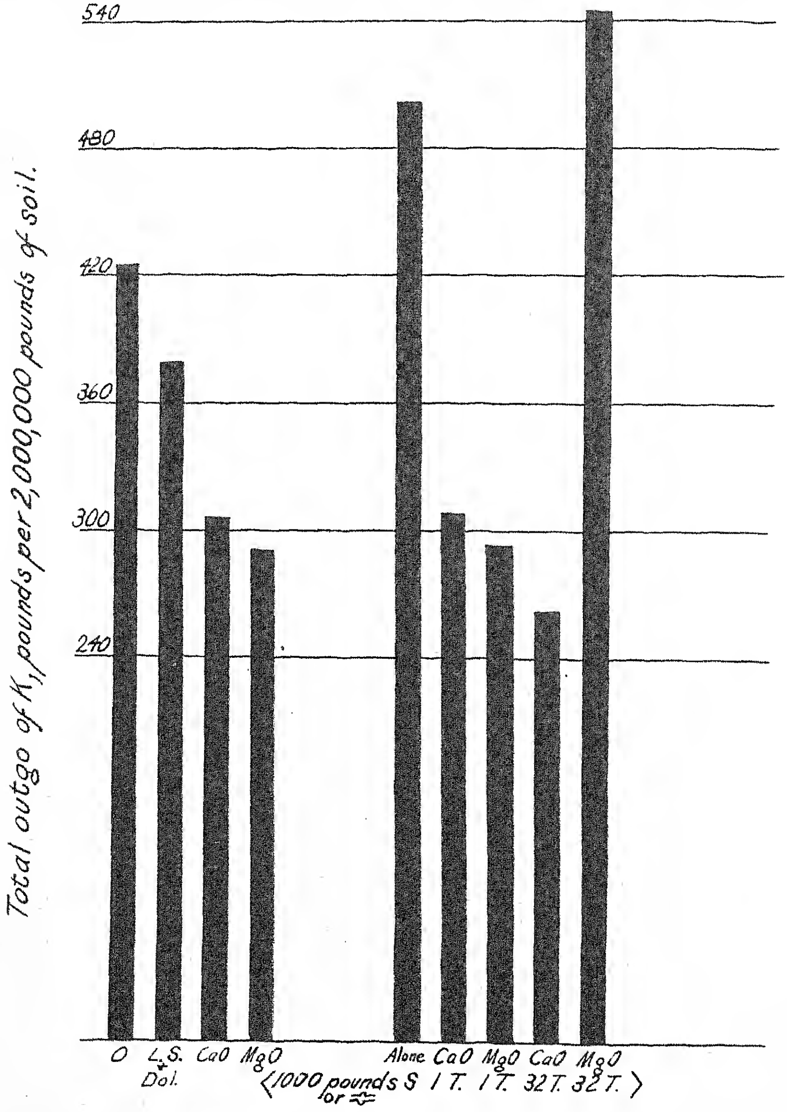

FIG. 2.—Influence of residues from additions of calcic and magnesic materials, alone and with supplements of sulfur, to a brown clay loam, as in Fig. 1, upon retention of K from K_2SO_4 additions—annual additions of K at the rate of 370 pounds K_2SO_4 (200 pounds K_2O, 166 pounds K) 13th–18th years, inclusive.

duced a decrease in the outgo of K below the amount that passed from the several unlimed controls. This repressive effect of the several liming materials was in continued evidence during the 6-year period for all treatments of the first, or no-sulfur, group, the maximal effects being the minus aggregate value of 173 pounds for the residues from the 1⅞-ton MgO treatment. The recovery from the additions to the previously untreated soil was 569 pounds short of the 996-pound addition of K, whereas the average of outgo totals for the six residues of the first group was 668 pounds. This means that the average repressive effect exerted by the six liming treatments was 99 pounds of K for the 6-year period.

In the three series that received the sulfur supplements in 1917, along with the liming treatments, the residues from the 32-ton CaO additions prevented a marked increase in outgo of K until after the third year. It was during this period, however, that a markedly divergent effect was induced by the residues from the 32-ton additions of MgO. This signal and sole divergence for units 61, 66, and 71 of the last three groups continued during the last 4 years.

The averaged cumulative effects induced by the several liming materials during the 6-year period are shown in Figs. 3 and 4 in which the results for the comparable or identical liming treatments, with and without sulfur supplements, are grouped. In both figures

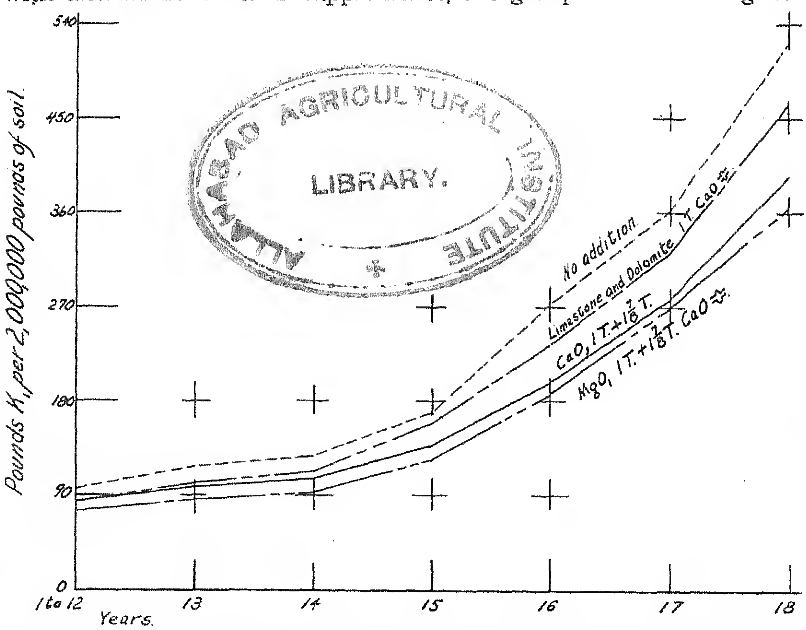

FIG. 3.—Cumulative outgo of K from a brown clay loam that received six annual additions of K_2SO_4 at rate of 370 pounds (200 pounds K_2O, 166 pounds K), as influenced by residues from limestone-dolomite, CaO, and MgO added 12 years before first addition of K_2SO_4. Limestone and dolomite, 1-ton CaO-equivalence averaged; CaO, 1-ton and 1⅞-ton averaged; MgO, 1-ton and 1⅞-ton CaO-equivalence averaged.

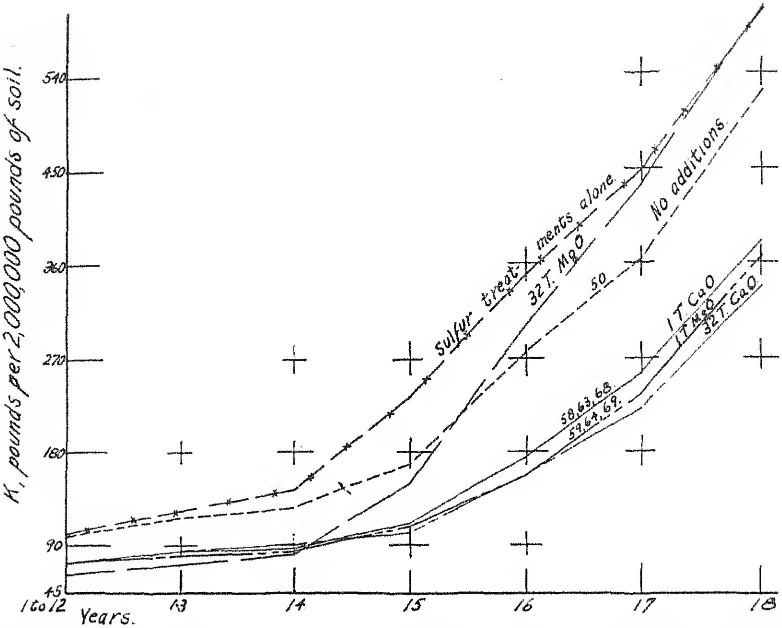

FIG. 4.—Cumulative outgo of K from a brown clay loam that received six annual additions of K_2SO_4 at rate of 370 pounds (200 pounds K_2O, 166 pounds K) as influenced by residues from incorporations of CaO and MgO and 1000 pounds of S, in three forms, that had been made 12 years before the first addition of K_2SO_4. Averages for CaO at 1 7/8-ton and 32-ton rates, with constant supplement of sulfur in forms of $FeSO_4$, pyrite, and S. Averages for MgO at 1 7/8-ton and 32-ton equivalent rates, with constant supplements of sulfur in forms of $FeSO_4$, pyrite, and S.

the starting points are the termini of the cumulative curves previously obtained for the first 12-year period during which no additions of potassium had been made. The variations in totals and in concentrations shown in the last column in the two sections of Table 1 warrant conclusions which may be summarized as follows: An increase in acidity—in parallel with a marked increase in outgo of native supplies of Ca + Mg (Table 2)— caused the unlimed controls to yield more K, or to fix less, than in the case of the soil that received no treatment save the six additions of K_2SO_4. The residue from each and every addition of limestone and of dolomite and of CaO at the three rates, 1 ton, 1 7/8 ton, and 32 tons, caused a fixation of K greater than that induced by the unlimed soil. The same repressive effect upon outgo was registered by the smaller residues from the lighter treatments of MgO at the CaO ≏ rates of 1 ton and 1 7/8 tons. These two statements as to the fixing power exerted by the all residues of CaO and the light residues of MgO are true for the liming materials alone and also with the supplements of the three forms of sulfur. After the third addition of K_2SO_4, however, the residues from the 32-ton additions of MgO registered an effect opposite to that registered upon K outgo from native supplies dur-

ing the first 12 years before the K_2SO_4 additions and also subsequent to the first two annual additions. The final result was a distinct acceleration and a marked enhancement in outgo of K. The maximal values for final annual concentration and total outgo of K was registered by the 32-ton MgO incorporations.

RELATION OF Ca + Mg OUTGO AND CONCENTRATIONS TO THOSE OF K

It is pertinent to compare the amounts of the alkaline earths and of K leached during the initial 12-year period with the corresponding values found for the subsequent period of 6 years. A similar comparison for the concentrations of Ca + Mg and K in the leachings obtained during the 12-year and 6-year periods is likewise germane. It has been pointed out (3) that the leachings from CaO additions to this type of soil will show a decrease in outgo of magnesium and that MgO additions will cause a decrease in the outgo of calcium. Table 2 gives the combined Ca + Mg values in terms of $CaCO_3$ for rainwater increments, for total outgo, and also for concentration in the leachings for the 12-year period and for the succeeding 6-year period in juxtaposition to the corresponding K values. The averaged concentrations of Ca + Mg in the leachings from the different liming materials are shown graphically for the two periods of 12 and 6 years in Fig. 5. Corresponding concentration values for the K content of leachings for the same two periods are shown in Fig. 6.

In the no-sulfur series the average concentration of Ca + Mg was 60.5 p.p.m. $CaCO_3$-equivalence during the first 12-year period and 61 p.p.m. for the following 6 years, with respective average annual rainfalls of 51 and 51.5 inches. The average annual increment of Ca + Mg from rainwaters was 79 pounds per acre surface for the first 12 years and 112 pounds for the last 6-year period. The replacement of Ca and Mg by the K of the added K_2SO_4 and the larger quantity of Ca + Mg derived from rainwaters during the last 6 years tended to maintain the outgo of the alkaline earths from the no-sulfur group. Since each of the unlimed sulfur-treatment controls had suffered a marked depletion in native bases because of the enhanced outgo of Ca and Mg as sulfates, especially during the early years of the 12-year period, a decrease in the Ca + Mg outgo from these units during the last 6-year period was inevitable. This sulfate effect from the sulfur additions—equivalent to 4,250 pounds of $CaSO_4$, or 3,125 pounds of $CaCO_3$—was evidenced by the immediate increase in outgo of SO_4 induced by $FeSO_4$ and the protracted effect induced by the sulfofication of the oxidizable materials, pyrite and elemental S (5), was also apparent in the concentrations of Ca + Mg in the leachings from the light additions of CaO and MgO during the final 6 years. For that period the Ca + Mg concentrations in the leachings from the light additions were practically the same, irrespective of the sulfur supplements. The SO_4 outgo was determined for each of the 18 annual periods, but the results are not essential in the present discussion and they will not be given.

The main cause for the ultimate decrease in the outgo of Ca + Mg from the 32-ton units was the large outgo of Ca from the initial CaO

TABLE 2.—*Total and average annual outgo of Ca + Mg and K and their concentrations in the leachings from a clay loam during a 12-year period subsequent to additions of calcic and magnesic materials, and during a subsequent 6-year period of annual additions of 200 pounds of K_2O per acre.**

No.	Treatment	Ca + Mg outgo as $CaCO_3$‡						Potassium outgo as K					
		Lbs. per 2,000,000 lbs. of soil				Concentration, p.p.m.		Lbs. per 2,000,000 lbs. soil				Concentration, p.p.m.	
		Total		Av. annual				Total		Av. annual			
		First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.	First 12 yrs.	Next 6 yrs.
50	None	3,257	1,640	271	273	44.4	49.5	101	427	8.4	71.2	1.37	12.90
51	Limestone	3,712	1,988	309	331	50.3	55.6	95	400	7.9	66.7	1.30	11.37
52	Dolomite	3,934	2,073	328	346	52.9	59.0	79	365	6.6	60.8	1.07	10.38
53	CaO, 1 ton	3,892	1,961	324	327	53.6	55.8	87	334	7.3	55.7	1.20	9.54
54	CaO, 1 7/8 ton	5,040	2,229	420	372	71.5	67.4	87	286	7.3	47.7	1.24	8.63
55	MgO, 1 ton‡	4,130	2,118	344	356	57.7	62.1	73	328	6.1	54.7	1.02	9.62
56	MgO, 1 7/8 ton‡	5,551	2,258	463	376	76.8	66.1	83	254	6.9	42.3	1.15	7.43
57	$FeSO_4$ alone	4,907	1,249	409	208	71.1	39.0	99	533	8.3	88.8	1.44	16.62
58	$FeSO_4$ + 1 ton CaO	6,577	2,025	548	338	94.6	61.5	74	344	6.2	57.7	1.06	10.43
59	$FeSO_4$ + 1 ton MgO	7,104	1,958	592	326	103.8	60.1	79	306	6.6	51.0	1.15	9.41
60	$FeSO_4$ + 32 tons CaO	15,724	5,159	1,310	860	259.8	168.7	77	292	6.4	48.7	1.26	9.54
61	$FeSO_4$ + 32 tons MgO	28,137	6,244	2,345	1,041	478.0	228.0	69	577	5.8	96.2	1.17	21.08
62	Pyrite alone	5,175	1,303	431	217	74.8	43.9	102	506	8.5	84.3	1.46	17.02
63	Pyrite + 1 ton CaO	6,479	2,279	540	380	92.1	71.5	71	293	5.9	48.8	1.01	9.18
64	Pyrite + 1 ton MgO	6,555	2,340	546	390	91.3	68.9	67	304	5.6	50.7	.93	8.95
65	Pyrite + 32 tons CaO	17,981	5,172	1,498	862	283.6	176.9	70	254	5.8	42.3	1.11	8.70
66	Pyrite + 32 tons MgO	28,649	6,093	2,387	1,016	473.1	220.6	61	532	5.1	88.7	1.00	19.24
67	Elemental S alone	5,071	1,303	423	217	71.9	40.8	105	469	8.8	78.2	1.49	14.67
68	Elemental S + 1 ton CaO	6,398	2,045	533	341	92.0	63.3	77	291	6.4	48.5	1.11	9.02
69	Elemental S + 1 ton MgO	7,563	2,063	630	344	107.4	63.3	74	274	6.2	45.7	1.05	8.41
70	Elemental S + 32 tons CaO	17,693	5,375	1,474	896	269.5	181.9	75	243	6.3	40.5	1.15	8.23
71	Elemental S + 32 tons MgO	29,720	6,044	2,477	1,007	498.7	221.6	59	519	4.9	86.5	1.00	19.02
	Rainfall, inches	611.8 (948)†	308.8 (670)†	51.0 (79)†	51.5 (112)†			611.8	308.8	51.0	51.5		

*2,000,000 pounds of soil.
†Values in brackets represent increments of Ca + Mg from rainwaters.

treatments and the still larger Mg outgo from the more soluble MgO (during and after carbonation) treatments with the consequential decrease in residues. But the diminution in Ca + Mg concentrations during the last 6 years cannot be utilized to explain the fact that initially the heavy MgO treatments registered a decidedly repressive

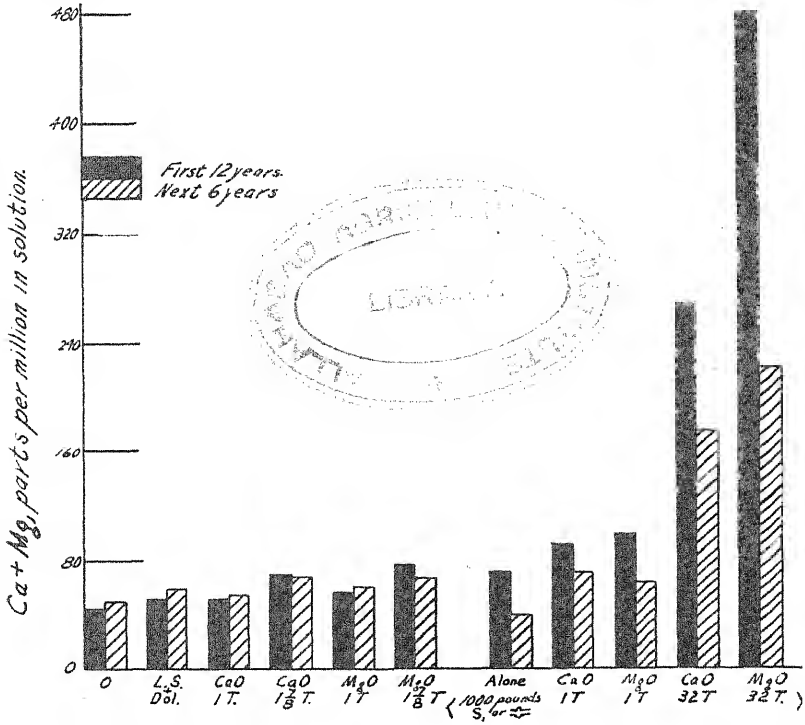

FIG. 5.—Average concentrations of Ca + Mg as p. p. m. $CaCO_3$-equivalents in the rainwater leachings from a brown clay loam during the first 12-year period after additions of calcic and magnesic materials, alone and with three forms of sulfur, in comparison with the average concentrations during the succeeding 6 years of annual additions of K_2SO_4 at the rate of 370 pounds per 2,000,000 pounds of soil.

effect and later an accelerative effect upon outgo of K, since the Ca + Mg concentrations of from 60 to 70 p.p.m. $CaCO_3$ equivalence from the light additions of both CaO and MgO showed a decided fixation of K, or a decrease in the outgo of that element. With a considerable drop from the 12-year average of 271 p. p. m. Ca + Mg concentration for the heavy CaO additions to the 175 p. p. m. average for the same additions during the last 6 years, the repressive effect upon K outgo was still in evidence. The Ca + Mg concentration values for the 32-ton MgO units, 61, 66, and 71, during the last 6 years, were less than the corresponding concentrations shown by these heavy treatments during the first 12 years, but they were still materially greater (27%) than the Ca + Mg concentrations found for the leach-

ings from 32-ton CaO units. Nevertheless, the MgO units, 61, 66, and 71, show an ultimate effect the reverse of that shown by the heavy or 32-ton, CaO units, *viz.*, 60, 65, and 70.

Although the reversal in the initial effect induced by the heavy additions of MgO did not appear until after the beginning of the third

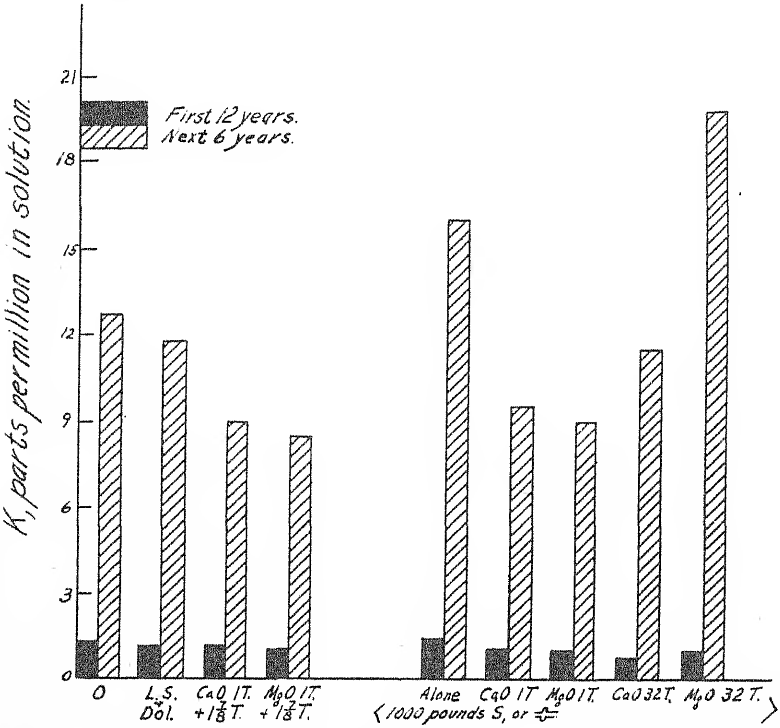

FIG. 6.—Average concentration of potassium as p. p. m. K in the rainwater leachings from a brown clay loam during the first 12-year period after additions of calcic and magnesic materials, alone and with three forms of sulfur, in comparison with the average concentrations during the succeeding 6 years of annual additions of K_2SO_4 at the rate of 370 pounds per 2,000,000 pounds of soil.

annual addition of K_2SO_4, the final accelerative effect during the last 4 years was so marked as to offset the initial repressive effect. The average concentration of K in the leachings from the 32-ton MgO units was 19.8 p. p. m. This was 6.8 p. p. m. greater than the concentration found for the untreated soil and 3.7 p. p. m. greater than the K value obtained for the leachings from the units that had become more acid and base-depleted, because of the additions of the three forms of sulfur. The unabsorbed residues of the CaO additions are known to have been converted completely to $CaCO_3$ and the unabsorbed residues of MgO had been converted to $Mg(OH)_2$ and in part to $3MgCO_3.Mg(OH)_2$ more than 10 years before the beginning of the last 6-year period during which annual additions of K_2SO_4 were made.

It is evident, therefore, that (a) initially, a low concentration of K was made still lower in the free soil water of a soil system of marked alkalinity and the corollary, the same alkaline soil system effected a marked fixation of added K and (b) subsequently (after one more addition), with an increase in concentration of K induced by further additions of K_2SO_4, there was less fixation of K by exchange between the build-up of Mg than between the added K and the build-up of H in the base-depleted control soil. This was true also for the still more acid sulfur-treatment controls.

It is difficult to explain why a soil saturated with Mg during a 12-year period of exposed contact with an excess of alkaline forms of magnesium could effect a fixation of K greater than that effected by a more acid system of the same soil, when the soil system was "bathed" with a low concentration of potassic salts, and then show the reverse effect, a lesser fixation capacity, when the concentration of K was increased by one more addition of K_2SO_4. In each case the surface addition of K_2SO_4 had to pass through the full depth of either Ca-or Mg-fortified soil before appearing in the leachings. When any chemical explanation is advanced to account for the behavior of the heavy MgO treatments, the question immediately arises as to why the CaO treatments failed to function in the same manner. The unabsorbed residues of MgO were more soluble than the unabsorbed residues of CaO and the Mg complexes hydrolyze more readily than the Ca complexes.

The heavy additions of the two materials, CaO and MgO, exert a distinctly divergent physical effect upon the soil. The former gives a granulation effect and a quick outgo of rain water, whereas the latter gives a sticky dispersed soil system and a protracted period of leaching. The effect that these physical variants may have upon the prevailing concentrations of solutes, including K, may hold an explanation of the anomaly noted. The explanation would be of academic interest, but no practical problem is involved. No such excessive treatment of MgO would be expected and the resultant toxicity upon plant growth could be foretold. A soil system of excessive alkalinity would be induced and a definite paucity of calcium would ensue as a result of the repression of the hydrolysis of calcic compounds and the "salting out" of calcium carbonate.

The fact remains, however, that the residues of all economic additions of MgO exercise the same repressive effect that is exercised by both light and excessive additions of CaO upon the solubility of soil potassium, as measured by rainwaters under conditions that admit of alternate wet and dry conditions. This holds for both low concentrations and those built up by additions of soluble potassium.

SUMMARY AND CONCLUSIONS

At the conclusion of a 12-year study of the effect of 21 full-depth incorporations of calcic and magnesic materials and 3 forms of sulfur upon outgo of Ca, Mg, K, and SO_4, the residual systems were given annual surface additions of potassium sulfate, at the rate of 200 pounds of K_2O per 2,000,000 pounds of soil during the succeding 6 years to determine the effect of the calcic and magnesic residues upon

the outgo and fixation of the added K. The K results are given in terms of pounds leached and p. p. m. concentration in the leachings, together with parallel Ca + Mg values for the 12-year and succeeding 6-year periods.

In each case some increase in outgo of K was obtained from the first addition of K_2SO_4; but in general, substantial increases in outgo were not registered until after the third addition.

The increases in outgo of K from the previously untreated soil and from the more acid sulfur-treatment controls were observed earlier and in greater totals than in the case of all economic additions of CaO, MgO, limestone, and dolomite.

Every addition of calcium at all rates effected a repression in outgo of K, the repressive effect becoming greater with increase in rates of liming. The light additions of MgO alone and with sulfur supplements exerted the effect comparable to that exerted by CaO. Initially, the 32-ton MgO additions exerted the same repressive effect that they had registered upon the native supplies of K during the preceding 12-year period; but, beginning with the third year, the 32-ton treatments greatly accelerated and enhanced the totals for K outgo.

The concentrations of Ca + Mg in the leachings from the light additions of burnt lime, limestone, dolomite, and MgO during the first 12-year and the subsequent 6-year period were comparable, as explained by K-Ca + Mg exchange and greater increment from rainwater during the latter period. The units that received the initial incorporations of $FeSO_4$, pyrite, and S showed a decided decrease in the concentration of Ca + Mg in the leachings of the 6-year period. But the concentrations found for the 32-ton additions of MgO were still materially greater than those found for the 32-ton additions of CaO. The reversal in the effect induced by the large residues of MgO after 14 years cannot be explained, therefore, by variant concentrations of Ca and Mg.

It is pointed out that this anomaly obtains only with excessive additions of magnesium oxide and that even after a period of 18 years the residues from all economic additions of Ca and Mg exert a repressive effect upon the outgo of K from a built-up supply of that element

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ANALYSIS OF *CROTALARIA JUNCEA* WITH SPECIAL REFERENCE TO ITS USE IN GREEN MANURING AND FIBRE PRODUCTION[1]

B. N. SINGH AND S. N. SINGH[2]

GREEN manuring and the cultivation for this purpose of quickly growing crops, chiefly of the leguminous order, has been a very ancient farm practice in most parts of the world associated with agriculture. Of the large number of crops used for this purpose, probably none answers the purpose better than *Crotalaria juncea*—a fairly rapid-growing plant, with a relatively short life cycle, capable of being raised without any special soil preparation. When ploughed down it requires a comparatively short time to decay, and besides acting as an important fertilizer it also yields fibre. The use of crotalaria as a green manuring and fibre crop has led the experimental agriculturists to advocate its cultivation in areas deficient in manurial constituents and in such other localities where other money crops may not be successfully grown for want of soil fertility. The scientific importance of this crop as a green manure in increasing soil fertility and its rôle in inducing physico-chemical changes in the soil which directly or indirectly bear upon plant growth have, however, been recognized only lately.

A critical survey of the literature indicates that the aspects along which work has been conducted during the last two decades centre round the determination of the best method of burying, the effect of addition of extra manure, and the influence of rainfall and water supply on the subsequent changes induced in the soil. Its utility in improving the physical configuration and the water-holding capacity of the soil, its usefulness as a reserve for the retention and circulation of plant food which would otherwise be washed away, as well as its rôle in acting as a substrate for the nitrogen-fixing bacteria are additional aspects along which useful work has been conducted. Little or no attention, however, has been given to the nature and the amount of materials formed at successive stages of growth of crotalaria and which constitute the substratum for all changes subsequent to the incorporation of the plant in the soil. Not infrequently the observed harmful after effects of green manuring are to be traced to the lack of this fundamental knowledge.

In order to determine, therefore, the period when the plant can yield the maximum amount of organic matter, contribute the most to the fertility of the soil in terms of nitrogen content, return to the soil the maximum amount of manurial nutrients, and provide the best quality of fibre, analyses of the plant as a whole and of its various parts were made at successive stages throughout the life cycle with reference to the more important inorganic and organic constituents. The data thus obtained are compared with parallel observations on

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[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication October 26, 1935.

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growth, conducted under field conditions, and suggestions made with regard to the stage in the life cycle of this plant when its use would result in the maximum possibilities of both soil fertility and fibre production.

METHODS AND MATERIALS

A pure strain of *Crotalaria juncea* was sown broadcast early in July with the onset of the rains on the experimental farms of the Institute. When the seeds germinated, seedlings of the same age and equal vigor were labelled and retained. For the determination of the dry matter, a large number of plants at successive stages of their development were carefully dug out of the soil with their root system intact, washed carefully in a stream of water, separated into their component parts, and dried to constant weight in a steam oven regulated at 100°C.

For the estimation of various organic constituents, a portion of the material was prepared after the method of Lind and Tottingham (5)[3]. Aliquot samples of the dried material so obtained were analysed with respect to different carbohydrates, celluloses, and fats. For the estimation of the essential elements, including calcium, potassium, magnesium, sulfur, and phosphorus, the official and tentative methods of analysis (1) have been used and need not be repeated here.

On the basis of the morphologieal characteristics, the entire life period of the plant has been segregated into four distinet stages for the purpose of these studies. The first or "juvenile" (young) stage is associated with scant vigor as demonstrated by dry matter production (Fig. 24), thin hairy stem, immature and few root nodules, and few small leaves from 20 to 25 mm in length, slightly reddish and hairy on the under surfaces. This stage lasts for 30 days after germination. The second or "adolescent" stage is characterized by rapid growth, a ramification of root hairs in all directions, thick yet flexible stem, branching of the stem with secondary and even tertiary arms, dense foliage, the whole forming a canopy, leaves bigger, 3 to 6 inches long and 1 to 3 cm broad, brighter in appearance and greenish in color, indicating better development of chlorophyll than in the first stage. During the present investigation this stage continued up to the 75th day where the initiation of the reproductive phase commenced, culminating in a third phase which is antecedent to the full-ripe stage, and which is designated as the "partial senescence" stage. It is associated with the flowering and setting of fruits, hard woody stems with mature fibre, yellowish leaves, shedding of the older leaves probably on account of the want of the nutritional availability. This stage lasted for 20 to 25 days after the adolescent stage, and merged into the full-ripe or "senescent" stage where more or less all the functional activities, a detailed discussion of which is beyond the scope of the present study, begin to sink and finally stop, resulting in the drying up of the plant. As this stage appeared at about the 105th day the experiments were discontinued. The results of the present findings are discussed both on the basis of the various physiological stages as well as age in days after germination.

The investigations were planned to determine the stage at which *Crotalaria juncea* abounds in maximum organic and inorganic constituents, the period at which the plant attains its maximum fibre content, the stage of development at which the best fibre quality is to be had, and a judicious selection of the period when the plant would have maximum possibilities for either manuring or fibre production, or both. A consideration of the rôle of manurial constituents in

[3]Figures in parenthesis refer to "Literature Cited", p.227.

organic synthesis and growth metabolism in general and other detailed studies on crotalaria will be taken up in a future communication.

RESULTS

FERTILIZING CONSTITUENTS

The percentage of most of the organic constituents synthesized by the plant at successive stages of its growth is found to increase continuously during the early part of the life cycle of the plant (60 days).[4] (See Fig. 4.) The reducing sugars, however, decline from the young to the senescent stage probably on account of their being continuously drawn upon to supply energy for the manifold plant activities as well as their conversion into other complex organic materials which ultimately make up the entire plant body. Fats, on the other hand, exhibit a decline only in the juvenile and the first half of the adolescent stage (45 days) when their use in nurturing the young seedlings brings down their percentage. When the seedlings resume their normal photosynthetic activity and a fresh supply of organic materials is available, the excess carbohydrates seem to be converted into fats, the content of which thus increases during the subsequent periods of the life cycle.

If crotalaria is to be used for green manuring, the plowing under of the plants at a stage when either of these organic constituents, *viz.*, reducing sugars or fats, are continuously decreasing would thus result in a decreased supply of organic matter in the soil, the lack of which may directly or indirectly fail to improve the anticipated physical characteristics of the soil as well as its water-holding capacity. With decreased availability of organic materials, as shown by Cates (2), humus formation may also be affected, which may, in turn, influence the physico-chemical reaction in the soil and induce such other changes in the liquid phase of the soil nutrients which may affect plant growth and thereby culminate in decreasing the fertility of the field.

A closer examination of the data reveals that certain organic substances, such as total carbohydrates and sucrose, attain a maximum when the plant is in its full adolescent stage (60 to 75 days). (See Fig. 4.) Fats and celluloses, however, constituting no less important a fraction of the organic matter, attain their highest values only towards the close of the life cycle. Were the burying of the crop, therefore, delayed till this stage, negative results would follow for at this stage the low values of both sucrose and total carbohydrates would greatly reduce the manurial value of the crop. Moreover, the presence of celluloses in larger quantities after the adolescent stage (Fig. 4) reduces the manurial value of the crop since the decomposition of the mature woody fibre and its thorough incorporation into the soil is not so easily secured, resulting in great damage to the succeeding crop through an attack of white-ants.

In all questions regarding soil fertility stress is laid on the available nitrogen in the soil. The loss incurred due to absorption by growing plants as well as to leaching frequently reduces the fertility level to such an extent that succeeding crops do not maintain good growth.

[4]Age of the plant in days after germination.

On all such soils, the use of crotalaria as a green manure is advocated as a source of nitrogen.

Determination of the nitrogen content reveals that with the growth of the plant the nitrogen increased gradually up to the latter part of the adolescent stage (60 days). (See Fig. 4.) The subsequent decline in the nitrogen content after this period, as well as the relatively low nitrogen content of the plant prior to this stage, clearly indicates that plowing under the crop before or after this critical period would reduce the maximum manurial efficiency of the crop in respect to nitrogen.

Besides nitrogen other inorganic constituents are also useful in one way or another in initiating good growth in plants. It is interesting to note that the percentage of ash in the dry matter gradually increases in the same direction as the percentage of nitrogen to reach a maximum when the plant is in its full adolescent stage (60 days). (See Fig. 4.) A decline in the ash content is to be noted after this stage, revealing thereby that the maximum amount of mineral elements present in the crop may be plowed under with advantage within two months after germination. The curves representing the percentages of the various elements show certain fluctuations with regard to their optimum amounts (Fig. 8), but calcium and potassium, which contribute much more than any other elements to the composition of the plant body, attain their maximums, like most of the organic constituents, when the initiation of the reproductive phase commences (60 to 75 days), and hence the plowing under of the crop during this period should provide the maximum amount of these important constituents to the soil.

As to the absolute quantities of these materials for different parts of the plant as well as for the plant as a whole, reference to Figs. 9 to 23 indicates that the majority exhibit a slow increase at first, followed by a steep rise which, in turn, rounds off to almost a level value to be succeeded very soon by a characteristic decline. The curves in every case resemble the time-weight curves for growth (Fig. 24). The maximum output of organic and inorganic constituents per plant is attained when the plant is in its partial senescent stage (90 days). (See Figs. 21 to 23.) Corresponding results are seen on reviewing the data calculated on an acreage basis for the entire plant (Table 1). If the addition of the highest amount of fertilizing constituents to the soil is the final goal of green manuring without taking into account the nature of the material, its rate of decomposition, and the fraction available to the succeeding crop, the entire plant may be plowed under in its partial senescence stage when it will add to the soil the highest quantity of nutrients obtainable in the entire life period of the crop. But quantity of nutrients is not the only criterion of successful green manuring because the hard woody stem at this stage, instead of leading to an improvement of the soil, will actually cause great damage, as previously mentioned.

On the other hand, the absolute quantities of the majority of the fertilizing constituents which contribute the most to the manurial efficiency of the plant both per acre and per plant (Table 1, and Figs. 9 to 20) for the leaves and roots attain their highest values only

TABLE 1.—*Fertilizing constituents in pounds per acre added to the soil by incorporating crotalaria at successive stages of its life cycle*

Age in days	Sample	Reducing sugars	Fats	Total carbohydrates	Sucrose	Celluloses	Nitrogen	Ash	Calcium	Potassium	Phosphorus	Magnesium	Sulfur
						Juvenile (Young) Stage							
1......	Tops and roots	0.6	1.08	1.6	0.26	0.36	0.54	0.62	0.16	0.05	0.03	0.03	0.12
	Entire plant	0.86	1.32	2.1	0.33	0.99	0.72	0.79	0.19	0.06	0.03	0.04	0.19
15......	Tops and roots	1.47	2.67	5.44	0.92	2.11	1.58	1.98	0.46	0.28	0.11	0.08	0.62
	Entire plant	2.01	3.10	6.63	1.15	3.16	1.94	2.27	0.56	0.29	0.12	0.09	1.02
30......	Tops and roots	18.0	30.3	69.9	12.04	13.3	22.4	32.7	9.30	3.97	1.44	0.86	10.39
	Entire plant	25.2	35.1	89.5	17.20	50.9	27.6	37.8	10.7	4.31	1.65	1.23	11.25
						Adolescent Stage							
45......	Tops and roots	51.8	46.1	227.1	47.8	59.7	81.2	108.5	42.6	22.80	2.79	3.39	28.11
	Entire plant	64.1	106.0	338.1	62.4	191.1	105.2	122.2	43.8	23.29	4.05	4.21	37.55
60......	Tops and roots	175.7	467.4	1,204.5	226.3	282.2	396.2	601.3	219.2	131.30	13.33	20.33	137.54
	Entire plant	267.9	676.3	2,064.2	480.6	1,376.9	683.8	962.5	332.9	202.52	21.32	21.25	168.11
75......	Tops and roots	216.3	745.1	1,687.1	417.7	489.2	473.9	840.6	276.1	188.30	15.71	35.88	178.04
	Entire plant	313.5	1,055.2	2,837.1	720.8	2,153.1	781.1	1,204.9	431.4	309.94	28.51	51.95	190.71
						Partial Senescent Stage							
90......	Tops and roots	231.6	954.2	1,649.6	362.3	433.3	447.3	573.8	232.7	197.67	15.94	40.46	130.00
	Entire plant	369.3	1,607.8	3,342.9	739.9	2,863.3	783.9	1,351.1	502.1	424.85	34.06	71.41	337.60
						Senescent Stage							
105......	Tops and roots	41.4	629.7	906.9	145.9	300.9	158.4	261.5	31.3	105.86	8.48	10.46	46.68
	Entire plant	151.9	2,220.9	3,055.8	509.5	3,350.5	473.8	1,264.2	170.6	455.43	31.91	43.59	169.52

at the time of the initiation of the first bud (75 days), whereas their percentage in dry matter, both in the entire plant and also in the various parts of the plant, is highest during the last fortnight of the adolescent stage (60 days). On the basis of the calculations and with the due consideration for the woody nature of the stem after the adolescent phase, it appears, therefore, that the green manuring either with the entire plant or with tops and roots alone at a stage coinciding with the initiation of the reproductive primordia (75 days) should result in maximum manurial value of the crop.

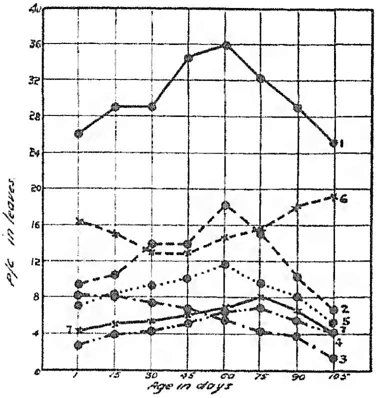

FIG. 1.—Percentage of various plant constituents in leaves. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

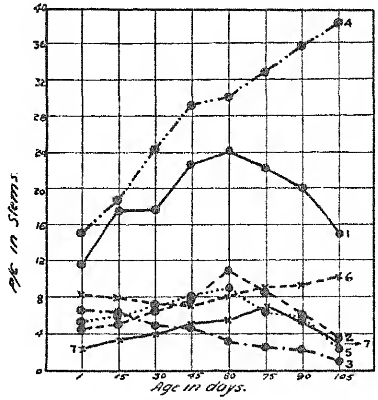

FIG. 2.—Percentage of various plant constituents in stems. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

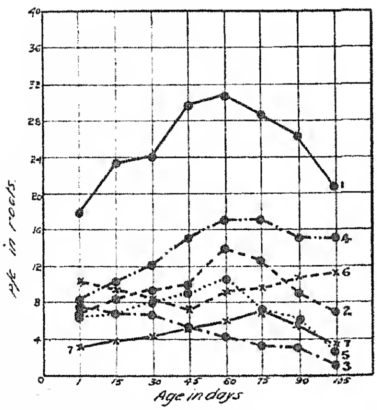

FIG. 3.—Percentage of various plant constituents in roots. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

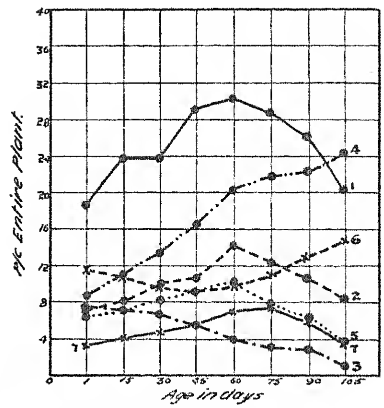

FIG. 4.—Percentage of various plant constituents in entire plants. (1) Total carbohydrates, (2) ash, (3) reducing sugars, (4) celluloses, (5) nitrogen, (6) fats, and (7) sucrose.

MANURIAL EFFICIENCY OF PLANT PARTS

To test the possibilities of green manuring with different parts of the plant, the root, stem, and leaf were analysed as to their more important organic and inorganic constituents at successive stages of growth. The leaf appears to be richest in the above materials (Figs. 1, 5, 9 to 20), while next in order are the root (Figs. 3, 7) and stem (Figs. 2, 6). The utility of the stem as a fibre-producing organ and of the leaf and the root, which are richer in the manurial constituents, for green manuring, was further tested by field experimentation. The effect of successful green manuring with tops and roots is extra-

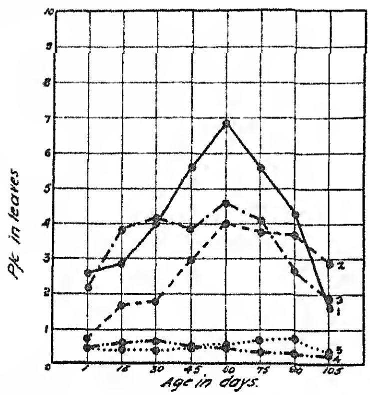

FIG. 5.—Percentage of inorganic constituents in leaves. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

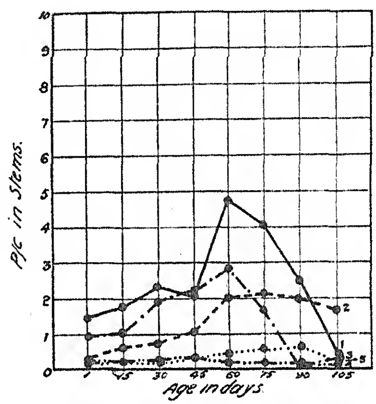

FIG. 6.—Percentage of inorganic constituents in stems. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

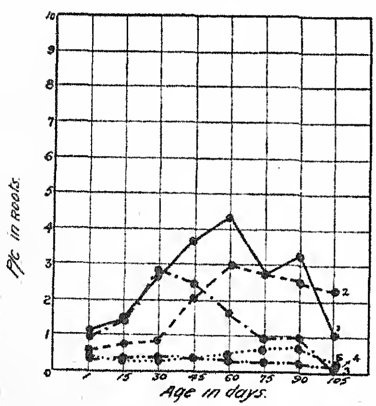

FIG. 7.—Percentage of inorganic constituents in roots. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

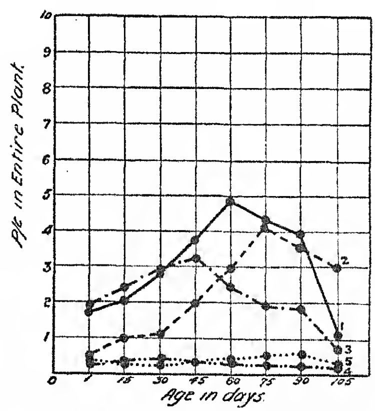

FIG. 8.—Percentage of inorganic constituents in entire plants. (1) Calcium, (2) potassium, (3) sulfur, (4) phosphorus, and (5) magnesium.

ordinary. The texture and the color of the soil are altered and the effect on the succeeding crop in luxuriance and rapidity of growth is remarkable, a discussion of which will be taken up in a later paper.

In the light of the present investigations it may be remarked that the leaf, containing simpler carbohydrates and proteins, is easily decomposed in the soil and adds to the fertility of the soil at a much earlier stage than the stem. The celluloses contained in the stem are highly complex materials, difficultly attacked by micro-organisms and, in consequence, decomposition of the stem requires a long time. These undecomposed stems result in too open a texture of the soil, causing considerable damage to the succeeding crop. It may thus be expected that green manuring with tender parts, such as the top

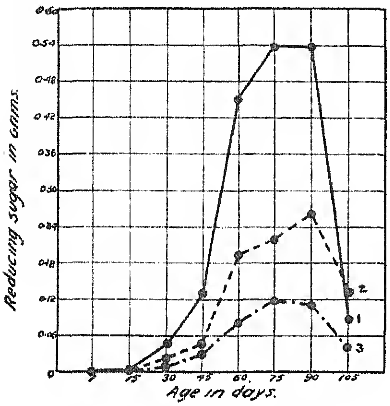

FIG. 9.—Reducing sugars in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

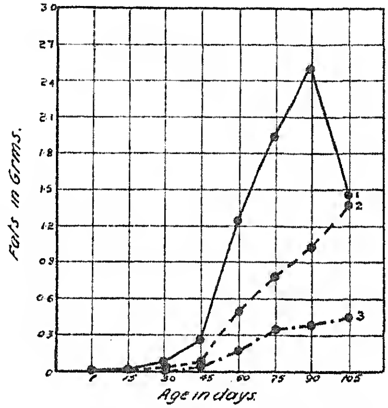

FIG. 10.—Fats in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

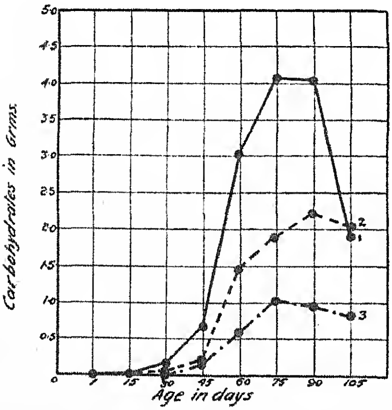

FIG. 11.—Carbohydrates in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

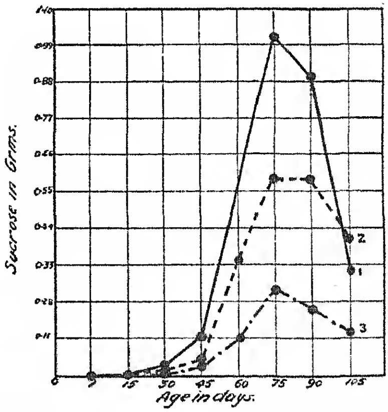

FIG. 12.—Sucrose in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

and the leaf, would result in a rapid availability of nitrogen compounds for the growth of the developing plant. On the other hand, manuring with stems, with their less rapid decomposition, adds much less organic and inorganic constituents than may be obtained from the leaves. The conclusion is thus obvious that greater manurial efficiency may be attributed to the leaf and that the stem, being less useful in this direction, may well be utilized for other purposes. The root, on the other hand, stands midway between the leaf and the stem in organic and inorganic constituents. The roots rot earlier than the stems and if incorporated with the soil along with the leaves may maintain a supply of readily available nitrogenous compounds. The decomposition of the roots at a slower rate may also help the plant

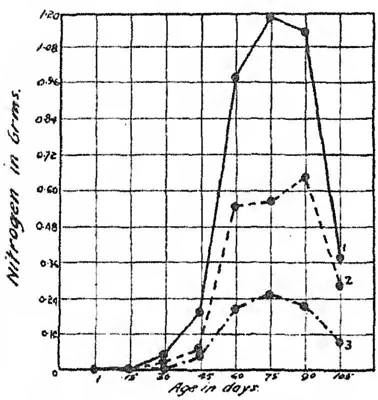

FIG. 13.—Nitrogen in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

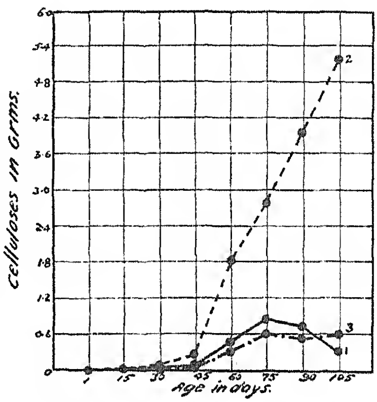

FIG. 14.—Celluloses in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

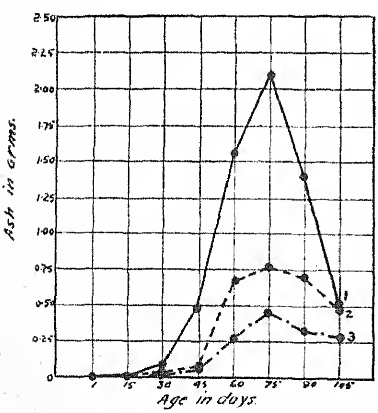

FIG. 15.—Ash in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

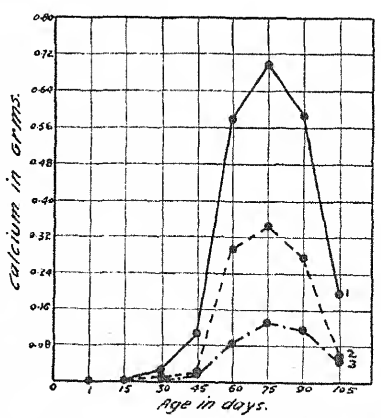

FIG. 16.—Calcium in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

in overcoming the nitrogen deficiency which may be felt at later stages of growth when the soil is relatively poor in nitrogen.

FIBRE CONTENT

To obtain an idea of the fibre content of the plant at successive stages of its growth, the plant was analysed with respect to celluloses. The quantity of fibre as judged by the amount of celluloses in the dry material was found to increase from the young to the senescent stage when the plant was 105 days old (Fig. 4). The stem showed the highest amount of celluloses (Fig. 2) and the leaf the least (Fig. 1). Field experiments reveal that the tonnage of the fibre is also highest at this stage. The length, tensile strength, and spinning value

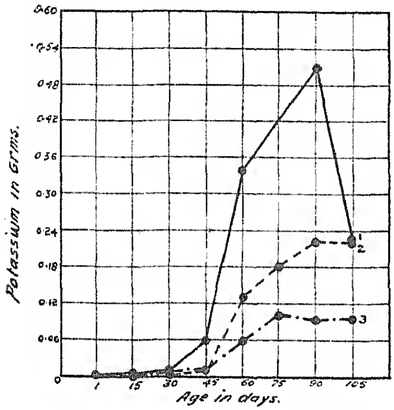

FIG. 17.—Potassium in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

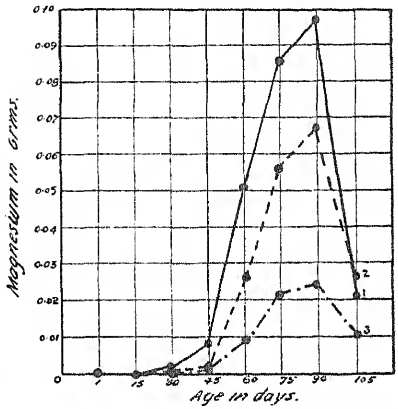

FIG. 18.—Magnesium in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

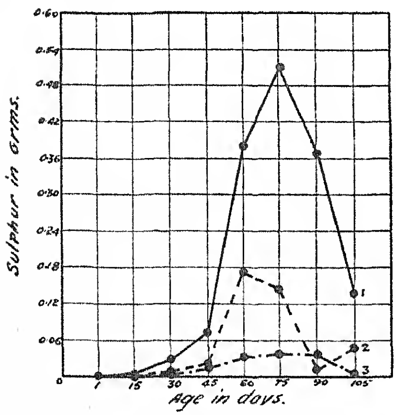

FIG. 19.—Sulfur in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

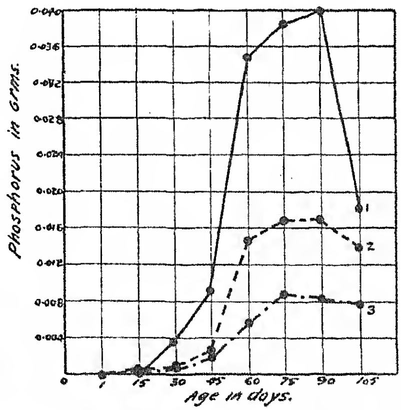

FIG. 20.—Phosphorus in grams in different plant organs. (1) Leaves, (2) stems, and (3) roots.

do not seem to follow the tonnage, however, as it is observed that the best results with regard to these qualities are only obtainable when the plant is in the adolescent stage (75 days), and that thereafter the development of wood considerably reduces the quality of the fibre. These observations are further supported by the investigations of Howard (3) and Joshi (4).

It seems desirable to mention that the cutting of the stems during the pre-flowering stage will result in better fibre quality and consequently will fetch a higher market value. On the contrary, if the aim of the cultivator is to obtain the maximum possibilities of both green

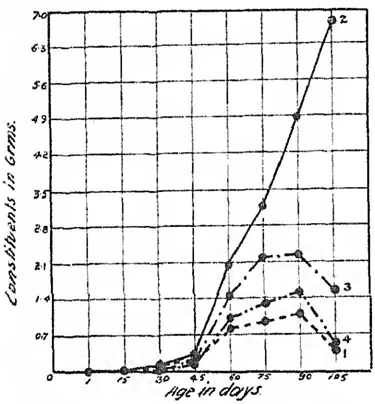

FIG. 21.—Constituents in grams in the entire plant. (1) Reducing sugars, (2) fats, (3) sucrose, and (4) calcium.

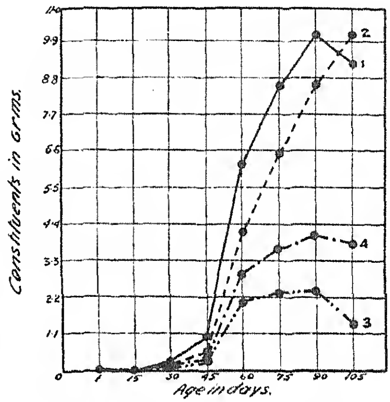

FIG. 22.—Constituents in grams in entire plant. (1) Total carbohydrates, (2) celluloses, (3) nitrogen, and (4) ash.

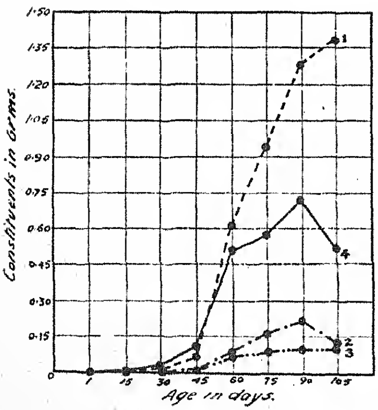

FIG. 23.—Constituents in grams in the entire plant. (1) Potassium, (2) magnesium, (3) phosphorus, and (4) sulfur.

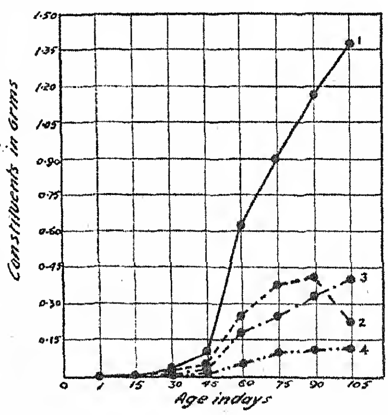

FIG. 24.—Production of dry matter in grams in the entire plant as well as different plant organs. (1) Entire plant (2) leaves, (3) stems, and (4) roots.

manuring and fibre production, it is suggested that the leaves and roots be plowed under for green manuring and the stems used for fibre production when the plant is in its full adolescent stage (75 days) when it is expected to add to the soil the highest amounts of organic and inorganic plant constituents, as previously discussed.

SUMMARY AND CONCLUSIONS

Crotalaria juncea was analysed as to its organic and inorganic constituents at successive stages of its life cycle. Simultaneous growth studies were also conducted and the data on the chemical composition of the plant calculated in terms of percentage of dry matter, of absolute weight of the plant, and the amount per acre to be added to the soil.

The percentages of organic matter, nitrogen, and other essential elements in general increased with the age of the plant and attained a maximum during the later part of the adolescent stage (60 to 75 days) both in the entire plant as well as various parts.

The absolute quantities of these materials for the entire plant, as well as the amounts calculated on an acre basis, attained maximum values when the plant was in its partial senescence (90 days), while for the different parts, especially the leaves and roots, the maximum was attained only at the initiation of the reproductive phase (75 days).

The analysis of the various parts clearly indicates that the leaves have the highest manurial efficiency, with the roots and stems in the order indicated.

Thus, on the basis of the development of the plant and its composition, it is inferred that the best period for green manuring would be when the adolescent stage is about at an end and when the reproductive phase commences.

The fibre content, as judged by the percentage of celluloses, reaches a maximum when the plant is in its senescent stage, but the best quality of fibre can only be had when the plant is in its adolescent stage.

If both green manuring and fibre production are desired, the leaves, tops, and roots could be plowed under with advantage while the stem could be used for fibre when the plant is 75 days old without in any way markedly affecting the fertility of the land.

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NITROGEN AND ORGANIC CARBON OF SOILS AS AFFECTED BY CROPS AND CROPPING SYSTEMS[1]

W. H. METZGER[2]

THE relative efficiencies of various crops and cropping systems in conserving soil nitrogen has been a matter of considerable interest to agronomists for many years. Many notable attempts have been made to measure such relative efficiencies. Only one of these attempts can be mentioned here. Salter and Green[3] have determined the effect of the following crops and cropping systems on the soil's supply of nitrogen and organic carbon: Corn, wheat, and oats each in continuous culture, a 5-year rotation containing a clover and timothy hay crop, and a 3-year rotation containing a clover hay crop. Furthermore, they have presented a means by which the efficiency of a rotation or an individual crop either in rotation or in continuous culture may be expressed mathematically. Assuming (a) that a given portion of the nitrogen and carbon of the soil, characteristic of the type of culture employed, is utilized in the production of each crop, and (b) that the gain in these constituents accounted for by the crop residues is roughly proportional to the size of the crop produced, the following equation was proposed by these workers: $N_t = N_o K^t$, in which N_t is the nitrogen content of the soil after "t" years, N_o is the nitrogen content at the beginning, and K represents the fraction of the nitrogen remaining after growing the crop a single year. Using the "K" values obtained from experimental data for the nitrogen and carbon of soils continuously cropped with various crops, the corresponding value for a crop used in rotation but not in continuous cropping can be calculated.

Determinations of nitrogen in the soil of many of the plats of the soil fertility project at the Kansas Agricultural Experiment Station were made in 1915, 1923, and again during the period of 1932 to 1934, and therefore an opportunity was afforded to test the assumptions involved in the formulation of the equation. The rates of change in the nitrogen content of the soil had probably become fairly well stabilized when the 1915 samples were taken, since six cropping seasons had elapsed after the establishment of the project before these samples were collected. For a series of 12 plats in a 3-year rotation of corn, cowpeas (or soybeans), and wheat, a comparison of the experimentally determined values with the values calculated

[1]Contribution No. 251 from the Agronomy Department, Kansas Agricultural Experiment Station, Manhattan, Kan. Also presented at the annual meeting of the Society in Chicago, Ill., December 6, 1935. Received for publication December 16, 1935.

[2]Associate Professor of Soils. The writer is indebted to Professor R. I. Throckmorton, Head of the Department of Agronomy, under whose direction the soil samples were taken in 1915 and 1923, and to Dr. C. O. Swanson, Head of the Department of Milling Industry, in whose laboratory the 1915 samples were analyzed.

[3]SALTER, R. M., and GREEN, T. C. Factors affecting the accumulation and loss of nitrogen and organic carbon in cropped soils. Jour. Amer. Soc. Agron., 25:622–630. 1933.

for 1923 and 1934, using the actual values for 1915 as a basis, is shown in Table 1.

TABLE 1.—*Comparison of the calculated and the experimentally determined nitrogen content of the soil of a series of plats devoted to a 3-year rotation.*

Plat No.	Nitrogen, 1923, pounds per acre		Nitrogen, 1934, pounds per acre	
	Calculated	Actual	Calculated	Actual
1	3,131	3,040	2,649	2,840
2	3,088	2,840	2,310	2,820
3	3,076	3,060	2,805	2,840
4	2,916	2,880	2,602	2,680
5	2,863	2,520	1,965	2,660
6	2,835	2,880	2,698	2,600
7	2,878	2,840	2,634	2,720
8	2,837	2,760	2,417	2,580
9	2,837	2,840	2,708	2,700
10	2,754	2,740	2,608	2,640
11	2,834	2,780	2,623	2,760
12	2,809	2,680	2,451	2,740

The soil samples taken in 1923 were sealed in Mason jars and were not analyzed until 1934. Unfortunately, a few of them were sealed before they became air-dry. Reducing conditions were produced and some loss of nitrogen may have occurred. The samples from plats 2, 5, and 12 were sealed moist and the "actual" nitrogen values for these plats for 1923 appear low. As a result, the calculated values for 1934 are, relatively, still lower. On the whole, however, the results show reasonably good agreement between the "actual" values and the calculated values. The "actual" values for 1934 are in most cases slightly higher than the calculated values, perhaps indicating that the rate of loss of total nitrogen has been checked and an equilibrium condition, characteristic of the cropping system and the climate, is being approached.

Nitrogen and organic carbon data were obtained in 1915 and again in the period of 1932 to 1934 for plats devoted to the following cropping systems: Continuous wheat, continuous alfalfa, a 3-year rotation of corn, cowpeas or soybeans, and wheat, and a 16-year rotation in which alfalfa occupies the land for 4 years, and a 3-year rotation of corn, wheat, and wheat[4] takes up the remaining 12 years. In each of these cropping systems the entire crop production is removed from the land. Soybeans were substituted for cowpeas in the 3-year rotation in 1929, hence in the period represented in this study four cowpea crops and two soybean crops were grown in this rotation. The soybean crop is drilled in rows, 7 inches apart, and removed as hay and the cowpea crops were handled likewise. The nitrogen and organic carbon data are shown in Table 2.

"K" values were obtained for wheat and alfalfa in continuous culture and by applying these to the 16-year rotation data the corresponding value for corn was determined. The equation then

[4]Originally corn, corn, and wheat, but changed in 1921.

TABLE 2.—*Nitrogen and organic carbon in the soil* of unfertilized plats under various cropping systems, average of 4 plats for each cropping system.*

Crop or cropping system	Nitrogen in pounds per acre for the year indicated		Organic carbon in pounds per acre for the year indicated	
	1915	1934	1915	1934
16-year rotation......	3,610	3,150†	40,700	32,880†
3-year rotation.......	3,065	2,705	38,700	27,890†
Continuous wheat.....	2,685	2,404†	38,350	29,750
Continuous alfalfa.....	2,550	2,910	32,050	31,560

*Surface soil (0–6 2/3 inches)
†1932

became $N_{1932} = N_{1915} K^5_{corn} K^8_{wheat} K^4_{alfalfa}$.[5] Since K_{corn} was the only unknown, its value could be calculated. This calculated value for corn applied to the data from the 3-year rotation, along with the "K" value for wheat in continuous culture, gave the "K" value for cowpeas (or soybeans). The difference between the "K" value for a given crop or cropping system, expressed as percentage, and 100 represents the loss or gain of the nitrogen or carbon, as the case may be, expressed on a yearly basis. The values so obtained for the various crops and cropping systems are shown in Table 3.

TABLE 3.—*Percentage annual gains and losses of nitrogen and organic carbon of the soil as affected by crops and cropping systems.*

Crop or cropping system	Percentage annual gain or loss	
	Nitrogen	Organic carbon
16-year rotation..................	—0.82	—1.24
3-year rotation...................	—0.66	—1.69
Wheat, continuous................	—0.64	—1.18
Alfalfa, continuous................	+0.71	—0.10
Corn (calculated)..................	—2.28	—2.27
Cowpeas (calculated)..............	+0.94	—1.72

The analyses for 1915 were made during that year and were not made by the same analyst who worked with the 1934 samples. The method used for nitrogen determinations, however, was substantially the same and it is believed the results are strictly comparable. In the case of the carbon data the methods differed. The 1915 results were obtained by the dry combustion method, while the wet oxidation method as outlined in Methods of Analysis (A. O. A. C., Ed. 2) was used in 1934, owing to a lack of equipment needed in the dry determination.

The results, including the calculated data, indicate that corn in continuous culture is nearly 3 times as destructive of the soil's

[5]In the 17 cropping seasons here represented, alfalfa occupied the land during the years 1926, 1927, 1928, and 1929.

nitrogen as the 16-year rotation and 3.5 times as destructive as the 3-year rotation or continuous wheat. It is probable that several factors enter into the causes for the more rapid disappearance of nitrogen under corn than under wheat, but in the case of these experiments, at least, the greater extent of erosion on corn land as compared to wheat land is undoubtedly of major importance.

The results for carbon, while possibly showing greater losses than would have appeared had both groups of determinations been made by the same method, are at least comparable among themselves. The trend of the carbon changes is similar to that of the nitrogen changes. Again continuous corn is indicated by the calculated data to be the most destructive cropping system studied and the presence of this crop in the rotations renders them fully as destructive or slightly more so than continuous wheat.

It is interesting to note that while alfalfa has caused gains in the nitrogen supply of the soil and about maintained the carbon content, cowpeas (or soybeans) are indicated to have increased the nitrogen slightly more per year than alfalfa but to have effected a distinctly greater loss of carbon. Since the values for cowpeas (or soybeans) could be arrived at only by employing the calculated values for corn, they may be subject to serious error. There have been very few data presented, however, which offer satisfactory evidence that soybeans or cowpeas, provided serious erosion is prevented, may not as effectively conserve or increase nitrogen of the soil as alfalfa over the period of time the crop actually occupies the land. These data suggest that the question may at least be worthy of further study. The indicated loss of carbon under cowpeas is possibly too great for reasons given previously, but it is perhaps significant that, although all crops and cropping systems have either about maintained or slightly reduced the carbon: nitrogen ratio since 1915, the greatest reduction occurred in the case of the 3-year rotation.

Data presented by White[6] and by Salter and Green[7] show a close relationship between the organic matter content of the soil and the total crop production over a period of years. The data for unfertilized plats of the soil fertility project of the Kansas Experiment Station show a very close relationship between total nitrogen and crop production over a period of 25 years. A similar relationship is shown between organic carbon and crop production. The data for total nitrogen and crop production are shown in graphic form in Fig. 1. The correlation is extremely high, $r = .978 \pm .008$. The regression line extended shows a value for the residual nitrogen with zero crop production of about 1,300 pounds, a value similar to that obtained by Salter and Green[8] for plats at the Ohio Experiment Station. The Kansas data also substantiate the Ohio data in the indication that each unit of crops produced contributes about the same to the soil's supply of nitrogen and organic matter regardless of the yield. In the data here presented it appears this was true with respect to the three

[6]White, J. W. Crop yields in relation to residual soil organic matter. Jour. Amer. Soc. Agron., 23:429–433. 1931.

[7]*Loc. cit.*

[8]*Loc. cit.*

cropping systems, i.e., 16-year rotation, 3-year rotation, and continuous wheat, in spite of the fact that one of these systems included alfalfa, one had soybeans, and the third had no legume. This fact may be interpreted as an indication that the nitrogen in the soil of the unfertilized plats of these cropping systems has become fairly

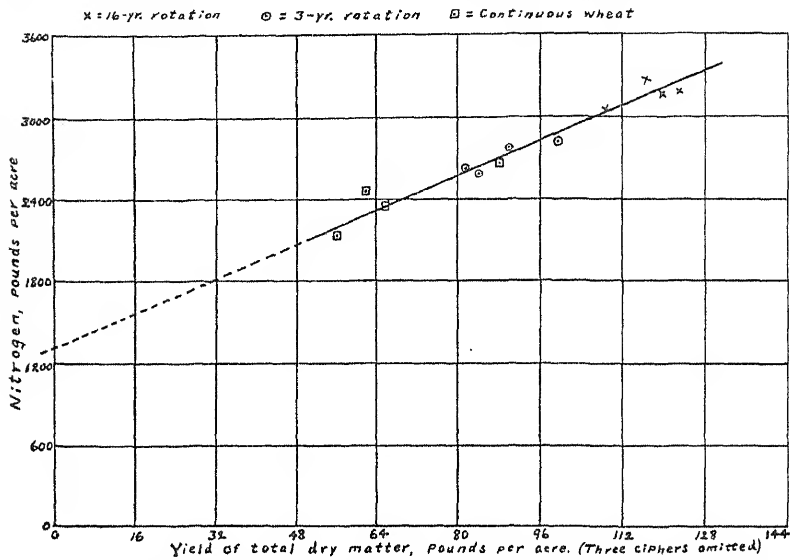

FIG. 1.—Relation of total crop production to the total nitrogen of the soil of unfertilized plats.

stabilized at a point characteristic of the cropping system in each case. It was pointed out on a preceding page that the retarded rate of decline of the soil's nitrogen during the period of 1923 to 1934 as compared to the rate for 1915 to 1923 also indicated such a stabilization.

Equilibrium conditions with respect to the soil's nitrogen supply are apparently approached rather rapidly under the soil and climatic conditions represented by these experiments. This is indicated by the fact that manure applications amounting to 40 tons in each of the two rotations and 60 tons in the case of continuous wheat have apparently failed to increase the nitrogen supply of the soil. In the continuous alfalfa experiment, 120 tons of manure during the same period of time have produced some increase in soil nitrogen but scarcely more than could be accounted for by the increased crop residues.

SUMMARY

Studies have been conducted at the Kansas Experiment Station to determine the effect on the soil nitrogen and organic carbon of the following crops and cropping systems: Wheat continuous, alfalfa continuous, a 3-year rotation of corn, cowpeas (or soybeans), and wheat, and a 16-year rotation in which alfalfa is grown for 4 years

and a 3-year rotation of corn, wheat, and wheat takes up the remaining 12 years. Corn was indicated to be much more destructive of nitrogen and carbon than any other crop or cropping system. Both alfalfa and cowpeas appear to have added to the soils nitrogen supply, but the latter was more destructive of carbon than the former. Continuous wheat produced about the same effect as each of the two rotations.

Total crop production over a period of 25 years and total nitrogen of the soil were shown to be highly and positively correlated. Manure applications failed to produce significant increases of nitrogen or carbon which could be attributed directly to the manure and not to increased crop residues. The nitrogen of the soil of the experimental plats studied appears to be definitely approaching an equilibrium characteristic of the crop or cropping system employed.

ARE UNIFORMITY TRIALS USEFUL?[1]

H. H. Love[2]

FROM time to time the suggestion has been made that for a field which is to be used for cultural experiments or studies in crop rotation and soil fertility a uniformity study be conducted. By a uniformity study is meant that the field will be laid out in plats of the size and shape that are to be used in the actual experiments, and the entire field will be sown to the same crop. The field should be handled in as uniform a manner as possible and the study continued for several seasons. The plats will be harvested and the data used to determine the variability of the different plats. The question is, "Are such trials useful ?" Some uniformity trials have been conducted and others are being conducted at the present time, and this paper is presented in the hope that those who have data from uniformity trials may be willing to present them. If this is done it may be possible to determine, in general, how useful uniformity trials are.

Some have criticized the value of uniformity trials on the basis that the yields of the plats may not be relatively the same from crop to crop, or that the plats will not react in the same manner after the experiment has been started. The vast amount of data presented by Harris and Scofield (5),[3] Parker and Batchelor (8), Garber, McIlvaine, and Hoover (4), and Garber and McIlvaine (3), showing the general tendency for the plats studied to react in a similar manner from year to year, should serve, in part at least, to meet this criticism. Even if there were little tendency to this association of yields, uniformity trials would serve a useful purpose in indicating whether all parts of the field chosen are suitable for laying down permanent or semi-permanent experiments. How many doubts, and possibly worries, could have been eliminated if data were available from two or three crops preliminary to certain experiments. So, in serving to point out parts of a field unsuitable for experimental purposes, uniformity trials will be useful.

Recently, added interest has been taken in the problem of uniformity trials, especially with reference to the interpretation of the results from such trials. Sanders (9), Eden (1), Murray (7), Vaidyanathan (12), and Summerby (11) have made valuable contributions to the subject following the method of analysis outlined by Fisher (2) but published first, as far as the author of this paper can determine, by Sanders (9). This method consists of making application of variance analysis and the determination of the covariance.

The method may be illustrated with unpublished data furnished by R. J. Borden of the Hawaiian Sugar Planters' Association, giving the yields obtained from the same plats for three different crops in uniformity trials of sugar cane. Sixteen plats have been used in this illustration, but the method may be applied to any number of plats.

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[1]Paper No. 206, Department of Plant Breeding, Cornell University Agricultural Experiment Station, Ithaca, New York. Received for publication January 15, 1936.

[2]Professor of Plant Breeding.

[3]Figures in parenthesis refer to "Literature Cited", p.244.

The yields for 1931 and 1933, expressed in per cent, are given in Table 1.

TABLE 1.—*The application of the analysis of variance to data from uniformity trials, preliminary to the analysis of covariance.*

	Preliminary test				Total
	113	113	91	102	419
	102	109	105	102	418
	96	99	94	101	390
	98	99	94	82	373
Total	409	420	384	387	1,600

General mean = 100

	Experimental test				Total
	103	110	92	113	418
	94	103	101	92	390
	103	99	94	99	395
	105	104	94	94	397
Total	405	416	381	398	1,600

General mean = 100

Analysis of variance

Variation due to	Degrees of freedom	Sum of squares	Mean square or variance	Standard error
		Preliminary test		
Rows	3	378.5	—	—
Columns	3	226.5	—	—
Error	9	351.0	39.0000	6.24
Total	15	956.0	—	—
		Experimental test		
Rows	3	114.5	—	—
Columns	3	161.5	—	—
Error	9	336.0	37.3333	6.11
Total	15	612.0	—	—

For convenience in the analysis, these plats have been arranged in the form of a Latin square, but other methods of arrangement may be followed. We may consider the test for 1931 as the preliminary test and the results for 1933 as the results from the actual experiment. Applying the methods for the analysis of variance, we have the results as given in the lower part of Table 1. The analysis shows that the standard error per plat for the preliminary test is 6.24 and for the experimental test 6.11.

We may now proceed to determine the covariance between the yields of the preliminary test and the experimental test in the

following way. The covariance is the mean product of the deviations of two variates, the deviations being measured from the respective means. The values and the deviations in the preliminary test will be designated x and those in the experimental test y, and we will consider first the results from the rows. The mean of the row totals in the preliminary test is 400 and the total yield of the first row for the preliminary test is 419. Therefore the x deviation is 19. For the next row it is 18; for the third row, which gives a total yield of 390, it is —10; and for the fourth row it is —27. The y deviations for rows from the experimental test are determined from the mean of the row totals in the experimental test in the same manner. The squares of the x and y values and the products of x and y are obtained as illustrated in Table 2. In a similar manner the squares of x and y and the products of x and y are obtained for the columns for both the preliminary and experimental tests, and also appear in Table 2. These squares and products are summed and divided by the number of contributing units, giving the values to be used in the analysis of variance.

In addition to the results for rows and columns, it is necessary to have similar values for the individual plats, or the total. These are obtained by taking each plat in one test and determining its deviation from the mean of all the plats for that test. For example, the mean of the preliminary test is 100 and the first plat in that test yields 113, so the x deviation is 13. For the corresponding y plat in the experimental test the yield is 103 and the mean of the experimental test

TABLE 2.—*Illustrating the method of determining covariance and the effect of regression on adjusted yields.*

	x	y	x^2	y^2	xy
		Rows			
	19	18	361	324	342
	18	—10	324	100	—180
	—10	— 5	100	25	50
	—27	— 3	729	9	81
Σ..............	—	—	1,514	458	293
Dividing by 4, the number of columns contributing to the individual deviations............	—	—	378.50	114.50	73.25
		Columns			
	9	5	81	25	45
	20	16	400	256	320
	—16	—19	256	361	304
	—13	— 2	169	4	26
Σ..............	—	—	906	646	695
Dividing by 4, the number of rows contributing to the individual deviations.	—	—	226.50	161.50	173.75

TABLE 2.—*Continued.*

	x	y	x^2	y^2	xy
		Total			
	13	3	169	9	39
	13	10	169	100	130
	—9	—8	81	64	72
	2	13	4	169	26
	2	—6	4	36	—12
	9	3	81	9	27
	5	1	25	1	5
	2	—8	4	64	—16
	—4	3	16	9	—12
	—1	—1	1	1	1
	—6	—6	36	36	36
	1	—1	1	1	—1
	—2	5	4	25	—10
	—1	4	1	16	—4
	—6	—6	36	36	36
	—18	—6	324	36	108
Σ..............	—	—	956	612	425

Sums of Squares and Products

	Degrees of freedom	x^2	xy	y^2
Rows...............	3	378.50	73.25	114.50
Columns............	3	226.50	173.75	161.50
Error...............	9	351.00	178.00	336.00
Total............	15	956.00	425.00	612.00

Analysis of Variance of Adjusted Yields

Variation due to	Degrees of freedom	Sum of squares	Mean square or variance	Standard error
Rows...............	3	137.5175	—	—
Columns............	3	43.5391	—	—
Error...............	8	245.7322	30.7165	5.54
Total............	14	426.7888	—	—

is also 100, so the deviation for y is 3. The other values for x and y for the total are determined and together with their squares and products are shown in Table 2. These values are brought together in the summary. Subtracting the sums for rows and columns from the sum for the total, we obtain the residue, or the amount due to error.

From the values for x^2, y^2, and xy due to error we may determine the correlation coefficient, which will show the correlation between the yields of the plats for the different years. Having obtained the correlation coefficient, we may then determine the regression coefficient, b. Dividing the values for x^2 and y^2 by the degrees of freedom,

9, and extracting the square root, we obtain the standard deviations for x and y, which are 6.24 and 6.11, respectively. The correlation coefficient may then be determined from

$$r = \frac{\frac{\Sigma xy}{N}}{\sigma_x \ \sigma_y}$$

In this case N is the degrees of freedom, 9. Substituting the values for xy and for σ_x and σ_y, we have

$$r = \frac{\frac{178.00}{9}}{(6.24) \quad (6.11)} = .519$$

Substituting the necessary values in the regression equation for y on x,

$$y = r\frac{\sigma_y}{\sigma_x} x,$$

we have

$$y = .519 \ \frac{6.11}{6.24} \ x, \text{ or}$$

$$y = .508 \ x$$

Since for the purposes of the analysis we are interested only in the regression of y on x, this may be obtained directly, letting b equal the regression coefficient, or

$$b = \frac{\Sigma \ xy}{\Sigma x^2}$$

Substituting the necessary values, we have

$$b = \frac{178.00}{351.00} = .507$$

The slight difference in the values obtained for b is due to the handling of the decimals.

We may now use this regression coefficient, .507, to correct the values for rows, columns, and total, and thus obtain a new standard error of the experiment after the effect of regression has been eliminated. Since b is the regression coefficient, the comparisons of adjusted yields are obtained from comparisons of $y - bx$.

Now

$$(y - bx)^2 = b^2x^2 - 2 \ bxy + y^2$$

and to obtain the sum of the squares for any line from the values given in Table 2 under the title "sums of squares and products", the entries in the table are multiplied by b^2, $-2b$, and unity (the coefficients of x^2, xy, and y^2) and the products summed.

Multiplying the values of x^2, xy, and y^2 for rows, columns, and total by the values for b^2 (.257049), $-2b$ (-1.014), and 1, respectively, we have the results for the analysis of variance after the effect of regression has been eliminated, as given in the lower part of Table 2. Thus for rows we have

$$378.50 \times .257049 = 97.2930$$
$$73.25 \times -1.014 = -74.2755$$
$$114.50 \times 1 = 114.5000$$

The sum of these three products is 137.5175. The values for the columns and total are obtained in a similar manner. The degrees of freedom for rows and columns remain the same, but one degree of freedom has been used in determining the regression and therefore the degrees of freedom for the total are 14 rather than 15. Adding the sums of squares and degrees of freedom for the rows and columns and subtracting from the total, we have the residue and degrees of freedom as given in Table 2. Dividing the residue, 245.7322, by the degrees of freedom, 8, we have 30.7165, and extracting the square root we have 5.54 as the standard error of the experiment after the effect of regression has been eliminated. This may be compared with the standard error, 6.11, obtained before the effect of regression was removed.

The same result will be obtained if the predicted or calculated yields for y are obtained from $y - bx$ and these calculated yields used for the analysis of variance in the usual way. In this equation y is taken as the actual yield of the plat.

For example, for the first y plat we proceed as follows. The first x plat in the preliminary series yields at the rate of 113% of the mean yield, and the deviation from the mean is therefore 113—100, or 13. The adjusted yield for the first plat is obtained by substituting this value for x in the equation $y - bx$. The actual yield of the first y plat is 103, and we have $103 - (.507 \times 13)$, or 96.409, as the adjusted yield. The other adjusted yields are determined in a similar manner, and by applying the method of variance analysis we obtain the same standard error, 5.54, as by the shorter method in Table 2.

It should be pointed out that in using the equation $y - bx$ to obtain the adjusted yields, the degrees of freedom will be reduced from 15 to 14, since the value b has been obtained from the data. As b has been calculated from the values for error this reduction will be made in the degrees of freedom for error.

The foregoing illustrates the value of a preliminary trial in obtaining corrected yields for the plats and for determining a standard error for the experiment after eliminating the effect of regression. If the preliminary trial has been continued for several seasons or crops, the results for each year may be analyzed separately, or it is possible to combine the results for several years, determine the average, and use this average yield in making the analysis. To illustrate how this may be done, the yields for the same plats for the crop years 1929 and 1931 have been averaged and expressed in per cent, as shown in Table 3.

With these values the calculations are carried out exactly as explained before, and the sums of squares and products obtained for rows, columns, and total are given in Table 3. The regression, b, determined from x^2 and xy due to error, equals 216.25/250.50, or .863. From this regression, obtaining b^2 and $-2b$, the corrected values for the analysis of variance are determined and are given at the bottom of Table 3. It is seen that the standard error has been

TABLE 3.—*Application of the analysis of variance to yields adjusted on the basis of the yields of preceding crops.*

	The average yields of the crops for 1929 and 1931 expressed in per cent				Total
	106 102 97 95	110 107 97 99	95 106 95 99	108 99 99 85	420 414 388 378
Total......	400	414	395	391	1,600

Experimental Test, 1933

	103 94 103 105	110 103 99 104	92 101 94 94	113 92 99 94	418 390 395 397
Total......	405	416	381	398	1,600

Sums of Squares and Products

	Degrees of freedom	x^2	xy	y^2
Rows...............	3	306.00	86.50	114.50
Columns............	3	75.50	84.25	161.50
Error...............	9	250.50	216.25	336.00
Total............	15	632.00	387.00	612.00

Analysis of Variance of Adjusted Yields

Variation due to	Degrees of freedom	Sum of squares	Mean square or variance	Standard error
Rows...............	3	193.1003	—	—
Columns............	3	72.3146	—	—
Error...............	8	149.3171	18.6646	4.32
Total............	14	414.7320	—	—

reduced to 4.32 by combining the yields of the two preliminary trials.

Recently, Bartlett and Wishart have made certain suggestions as to refinement of methods of adjusting yields and these suggestions have been applied by Snedecor (10) in a recent publication. Fisher (2) in the fifth edition of his book does not follow these suggested methods but does add a further refinement to the method he published earlier. In this connection he says, "The value of b used in obtaining the adjusted yields is a statistical estimate subject to errors of random sampling. In consequence, although the quantities $y - bx$ are appropriate estimates of the corrected yields, they are of varying precision; the sums of their squares in the lines of the table

from which b has not been calculated do not therefore supply exact material for testing the homogeneity of deviations from the simple regression formula. This test we should wish to make if real differences of treatment had been given to our plots, ..."

Instead of adjusting all values on the basis of the regression, b, obtained from the estimate of error, Fisher adjusts the values for total and error on the basis of their own regression by deducting from $S(y^2)$ the quantity $(Sxy)^2/S(x^2)$. The adjusted value for treatment is then obtained by deducting the reduced value for error from the reduced value for total. This method of adjustment is applied to the sums of squares and products for the data in Table 2, omitting those for columns, and the results are given in Table 4. For purposes of illustration the rows may be considered as treatment.

TABLE 4.—*Adjustment of values from Table 2 according to method by Fisher.*

	Degrees of freedom	Sums of squares and products			Degrees of freedom	Reduced values	Mean square
		x^2	xy	y^2			
Rows......	3	378.50	73.25	114.50	3	118.2338	39.4113
Error......	9	351.00	178.00	336.00	8	245.7322	30.7165
Total.....	12	729.50	251.25	450.50	11	363.9660	———

For the reduced value for total we have

$$450.50 - \frac{(251.25)^2}{729.50} = 363.9660$$

The adjusted value for error is obtained in a similar manner, and it is noted that in each case one degree of freedom is lost. Subtracting the adjusted value and degrees of freedom for error from those for total, we have three degrees of freedom and a reduced value of 118.2338 for rows or treatment. The mean square of this reduced value is to be compared with the mean square of the reduced value for error. This refinement of method should be given consideration especially where treatments are concerned, and the methods of Bartlett and Wishart as applied by Snedecor (10) may also be of value in such cases.

Sanders (9) has shown that the variance of adjusted yields may also be calculated from the formula $V_{y.x} = V_y - \frac{(Cov_{xy})^2}{V_x}$.

In this formula $V_{y.x}$ is the variance of the adjusted yields, V_y and V_x are the variance values for y and x, and Cov_{xy} is the mean of the product deviations of x and y measured from their respective means. The value resulting from this formula is corrected for one degree of freedom used in obtaining the regression value. The increase in precision obtained as the result of using the previous records is then given by $\frac{V_y}{V_{y.x}}$.

Using the data from our first problem, we have from Tables 1 and 2

$$V_y = 37.3333 \qquad Cov_{xy} = \frac{178.00}{9} = 19.7778 \text{ and}$$
$$V_x = 39.0000$$

$$V_{y.x} = V_y - \frac{(Cov_{xy})^2}{V_x} = 37.3333 - \frac{(19.7778)^2}{39.0000} = 27.3035$$

Correcting for the one degree of freedom used in the regression, we have

$$V_{y.x} = \frac{9}{8} \times 27.3035 = 30.7164$$

as the variance of the adjusted yields. The precision is given by

$$\frac{V_y}{V_{y.x}}, \text{ or } \frac{37.3333}{30.7164} = 1.22.$$

The increase in precision gained by using the average of the preliminary yields for 1929 and 1931 is given by $\frac{37.3333}{18.6646} = 2.00$

This shows a very satisfactory increase in precision.

Another example from 48 plats of sugar cane, using the results from only one preliminary crop, showed some increase in precision. The precision constant is only 1.52 in this case, but even so, if long-time fertilizer trials are to be undertaken, it suggests that it may be advisable to continue the uniformity test one more year at least.

Data from the Illinois Agricultural Experiment Station supplied by Hopkins, Readhimer, and Eckhardt (6) with corn as the preliminary crop and clover as the experimental crop, have been studied and a precision factor of 1.41 obtained. Again, with some of the data presented by Harris and Scofield (5) with alfalfa as the preliminary crop and corn as the experimental crop, a precision factor of 1.46 was obtained.

Sanders (9), working with annual crops, has shown by this method of analysis that for one field the precision of an experiment would be increased by nearly 150% if the regression on the mean yield of the three previous years were used. Sanders says, "In this instance the gain is very considerable, and it is possible that under certain circumstances (e. g. with a restricted area, or where little assistance was available at any one time) it might repay the labour of 3 years uniformity trials, even though it would increase the work fourfold and the precision but little more than threefold: such a result must not however be expected in all cases . . . . . ." The other field studied by Sanders showed no constancy in yield.

Eden (1), working with tea, made application of this method and found that the standard error per plat for the experimental field without considering the regression was 10.93, while the standard error fell to 4.19 when the regression was considered. He concludes, "In terms of the precision index, the experiment with the regression is 6.81 times as accurate as that without; since the replication is fourfold, the corrected figures give an accuracy which could only be

expected from the crude data with a replication of twenty-seven and with the use of the regression this involves only twice the labour."

Murray (7), working with rubber and assuming five replications, found that considerable reduction was obtained by making use of the preliminary cropping records. The precision index was found to be 3.74 and he states, "In other words, if the year 1927 were to stand alone, the number of replications necessary to achieve the same degree of accuracy would be 5×3.74, or approximately 19." Murray emphasizes the importance of considering the preliminary data, as follows: "A practical point to be noted is that the regression is a more effective means of reducing error than the removal of positional variance; the elimination of rows and columns has only reduced the variance from 10,024 to 7,421, whereas the regression based on the total sums of squares (i. e. ignoring rows and columns) reduces it to 1,754. This suggests that results of some value can be obtained with rubber where previous records are known, but where the arrangement of the plots does not permit elimination of the positional effect." He concludes, "It is concluded that not only has the method of correction been of value in the particular instance investigated, but that a uniformity trial utilized in this way should be of practical value in any major field experiments with rubber."

Vaidyanathan (12), using data from tea plats, emphasizes the importance of making use of preliminary data when available and states, "From such an analysis of variance of preliminary yields, it is possible, for example, to know whether there is a significant variance in yields in 'rows' and 'columns' or again whether 'rows' and 'columns' themselves significantly differ. If it so happens that 'rows' show significant increase over 'columns', then the block arrangement of plots along 'columns' should be preferred and *vice versa*. Or again if both 'rows' and 'columns' show very high variances as compared to randomness, the size of the block should be appreciably reduced and the number of replications correspondingly increased. Thus the analysis of data of preliminary yields into 'block' variance and 'random' variance can always indicate an improved method of lay-out." With the data used, Vaidyanathan found that the improvement in precision resulting from the use of the preliminary crop yields was increased nearly 16 times and concludes, "Thus it is seen that where preliminary yields of experimental plots can be secured, it seems advantageous to explore them fully and make valid use of them. By using such data, not only is an 'improved' lay-out possible but there is a possibility of securing a 'greater' precision on which a more equitable comparison of 'treatments' should necessarily depend."

Summerby (11) says in conclusion to his study, "Under the conditions of this experiment the use of preliminary uniformity trials for the purpose of adjusting yields of subsequent experiments by regression is only rarely as effective in increasing precision as is the use of the same amount of land and labour in replicating the experiment in the year of the trial. Preliminary uniformity trials may, however, be useful in determining the plotting plans that will give the greatest precision. They may also prove useful in eliminating areas that are unsuited for experimental purposes."

Garber and McIlvaine (3) state, "The correlations presented ..... show very definitely that an appreciable amount of the total variation in the corn yields may be accounted for by the different levels of natural productivity that existed among the plats when the rotation experiments were begun, as measured by a uniformity crop. In view of this fact the experimental error might be reduced still further by analyzing the covariance between the yields of the uniformity crop and the corn yields obtained subsequently."

Fisher (2) states, "Analysis of covariance on successive yields on uniformly treated land shows that the value of the experiment is usually increased, but seldom by more than about 60 per cent, by a knowledge of the yields of the previous year. It seems therefore to be always more profitable to lay down an adequately replicated experiment on untried land than to expend the time and labour available in exploring the irregularities of its fertility."

In the light of recent studies, however, and especially from the results of Murray (7), where he found that regression or the use of preliminary data is a more effective method of reducing error than the removal of positional variance, such as blocks, it must be admitted that there are times when this method of using preliminary crop yields will be a very valuable addition to our experimental technic.

At the present time the data studied indicate that greater gains in precision are obtained from crops like tea and rubber, or in other words, where the plats have the same plants from year to year. This suggests that certainly for long-time experiments where orchard, forest, or similar crops are to be the experimental material, it would no doubt be of benefit to conduct some preliminary cropping trials.

For annual crops more data are needed to settle the question, but it would seem that certainly for such experiments as long-time crop rotation and soil fertility studies, preliminary cropping will be of value. If no gain in precision is obtained, at least the preliminary cropping should aid in improved lay-out. The fact that, for most of the cases studied to determine the permanency of plat variability, it has been found that there is a relation from year to year, would indicate that this problem should be investigated further. In other words, our present stand should be that of seeking further information rather than to conclude either that the method will always lead to greater precision or that the system of preliminary cropping will be of little value. Certainly, for indicating those parts of a field that should not be used for experiment and for suggesting a better lay-out, preliminary cropping will be useful, and for some fields and crops at least the data from preliminary cropping will lead to greater precision.

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THE COMBINING ABILITY OF INBRED LINES OF GOLDEN BANTAM SWEET CORN[1]

I. J. Johnson and H. K. Hayes[2]

WHEN only a few inbred lines of corn are available the usual method of determining how they can be used most advantageously is to make all possible combinations between them and select for commercial production the single, three-way, or double crosses that prove the most satisfactory. When many inbred lines are available it has proved desirable to test their combining ability and discard those that give low-yielding crosses on the average. The first method of determining combining ability consisted of a series of crosses of each inbred with 10 or 12 inbred lines used as testers. In 1932, Jenkins and Brunson[3] presented data to show that an open-pollinated variety could be used as a tester to determine the relative combining ability of inbred lines. Significant and fairly high correlations were obtained between the mean yields of inbred lines in several single crosses and the average combining ability of these same lines in top crosses. This has led to the use of top crosses as a means of selecting inbred lines with satisfactory combining ability.

The present study was made to determine the reliability of top crosses as a means of determining the combining ability of inbred lines of sweet corn. A study was made also of the relation between characters of inbred lines and their F_1 top crosses.

MATERIALS AND METHODS

In 1934, a group of 39 inbred lines, of which 31 were obtained from an eight-rowed canning type of Golden Bantam and 8 from a cross of two inbred lines, were selected for this study. The lines had been inbred for 6 to 12 years and were the most desirable lines remaining from the standpoint of vigor and other desirable plant characters. Since the majority of these lines, like those obtained from the earlier inbreeding studies with Golden Bantam lines at Minnesota, were sufficiently vigorous to be be used in commercial single crosses, these lines if crossed in all possible combinations to find the most desirable hybrids, would have necessitated making and testing 741 single crosses [$\frac{1}{2}n\ (n-1)$]. With a few exceptions, each of these lines was top crossed to the parental Golden Bantam variety, to Del Maiz, a medium-maturing, 10- to 16-rowed yellow sweet corn developed by the Minnesota Valley Canning Company, Le Sueur, Minnesota, and to a Del Maiz inbred line. The Golden Bantam and Del Maiz top crosses were separated into two groups and grown in single-row plats with three randomized replications at University Farm, St. Paul, Minn. The field distribution of the two groups was also randomized. The Golden Bantam and Del Maiz top crosses and the single

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[3]Jenkins, Merle T., and Brunson, Arthur M. Methods of testing inbred lines of maize in cross bred combinations. Jour. Amer. Soc. Agron., 24:523–530. 1932.

crosses with the Del Maiz inbred line were grown in single-row plats with two randomized replications at Le Sueur, Minn.

Eleven of the 39 lines obtained by selfing normal Golden Bantam were crossed in all possible combinations to make 55 single crosses. These were grown at University Farm in single-row plats with three replications in randomized blocks. The inbred lines used in the character study were grown in single-row plats with one plant per foot in two randomized replications at University Farm. The data discussed in this paper on the hybrids are based on the yield of cut corn from 3-stalk hills surrounded by hills of corn. Yield of mature ears and notes on several plant characters of the inbred lines were obtained from a character study of the inbred lines.

EXPERIMENTAL RESULTS

The data from this study will be presented and discussed in three separate parts, as follows: (1) The correlation between the yield of single crosses and the average yield of lines in all top crosses and in several single crosses; (2) the correlation between yields obtained from top crosses with the parental variety, with an unrelated variety, and with an unrelated inbred line; and (3) the correlation between several characters of the inbred lines and their average yield in top crosses and with an unrelated inbred line.

CORRELATION BETWEEN TOP CROSS AND SINGLE CROSS YIELDS

Since 11 of the inbred lines used in the top cross study had been crossed in all possible combinations, it was of interest to determine the correlation between the yield of these lines in top crosses and in F_1 single crosses. The 11 lines varied in their average top cross yield from 170 to 253 grams of cut corn per hill. A study of the combining ability of the lines was made in two ways, first, by the correlation between the yields of the 55 single crosses and the average top cross yield of the two parents, and second, by the correlation between the yields of the single crosses and the average yield of the two parents in 9 other single crosses. The results of these studies are given in Table 1.

TABLE 1.—*Comparison between the top cross yields and the average single cross yields as a means of measuring the combining ability of inbred lines.*

Characters correlated	n	Correlation coefficient
Average of parental lines in top crosses and single cross yields....................	55	$.4748 \pm .1044$
Average of parental lines in 9 single crosses and single cross yields................	55	$.6991 \pm .0689$
Average yield of 11 lines in single crosses and in top crosses....................	11	$.7835 \pm .1221$

This phase of the present study is of particular interest since in the final analysis the proof of the validity of any method of determining the combining ability of inbred lines lies in the actual yields of hybrids made between them. From the correlations given in Table 1, it is evident that a fairly close relationship exists between

the mean yield of the parental lines in top crosses and the actual F_1 yield between them (r = .4748). Inbred strains producing high-yielding top crosses should then be expected to give the highest yielding single crosses. The relationship between the mean yields of the parental lines in nine single crosses to the yield of the F_1 single cross between them is likewise fairly close (r = .6991). The difference between these two coefficients is 1.8 times their standard error, and consequently it may be assumed that the estimation of combining ability of inbred lines by means of top crosses is about as accurate as their estimation on the basis of their mean yields when crossed with nine other lines used as testers. A high correlation coefficient of .7835 was obtained between the top cross yields of the 11 lines and the average yield of the 11 lines in their 10 single crosses.

In the final comparison made between the yields of the lines in top crosses and in single crosses, the 11 lines were classified into four groups on the basis of their average top cross yield. The lines in group 1 gave top cross yields of 170 to 194 grams per hill; those in group 2, 195 to 219 grams; those in group 3, 220 to 244 grams; and those in group 4, 245 to 269 grams per hill. The distribution of the single crosses made between inbred lines with different levels of combining ability as determined by top crosses is shown in Table 2. From an inspection of the yields from the various groups of crosses it is evident that the poorer combining lines crossed among themselves, i.e., group 1 x group 1 and group 1 x group 2, failed to produce high-yielding single crosses. Crosses made between poor combining lines and good combining lines, i.e., group 1 x groups 3 and 4 and group 2 x groups 3 and 4, gave a few good single crosses on the basis of the average yield of 257 grams per hill from the standard open-pollinated parental Golden Bantam. Crosses between the

TABLE 2.—*Distribution of yields from Golden Bantam single crosses made between inbred lines classified into four groups on the basis of their top cross yields.*

Groups crossed	No. of crosses	Distribution of single cross yields in grams per hill											Actual average, grams
		130	160	190	220	250	280	310	340	370	400	430	
Group 1 x Group 1	3	1	1	1	—	—	—	—	—	—	—	—	161
Group 1 x Group 2	3	2	—	1	—	—	—	—	—	—	—	—	147
Group 1 x Group 3	15	—	1	—	4	5	3	2	—	—	—	—	250
Group 1 x Group 4	6	—	—	—	1	3	1	1	—	—	—	—	260
Group 2 x Group 3	5	—	—	1	1	2	1	—	—	—	—	—	237
Group 2 x Group 4	2	—	—	—	—	1	1	—	—	—	—	—	274
Group 3 x Group 3	10	—	—	—	1	—	3	2	2	1	—	1	315
Group 3 x Group 4	10	—	1	—	—	1	3	4	—	1	—	—	284
Group 4 x Group 4	1	—	—	—	—	—	—	1	—	—	—	—	305

Group 1—cultures 4, 5, 9
Group 2—culture 10
Group 3—cultures 1, 2, 3, 8, 11
Group 4—cultures 6, 7
Top cross yield = 170 to 194 grams per hill.
Top cross yield = 195 to 219 grams per hill.
Top cross yield = 220 to 244 grams per hill.
Top cross yield = 245 to 269 grams per hill.

better combining lines, i.e., group 3 x groups 3 and 4 and group 4 x group 4, gave most of the really superior single crosses. On the basis of this test, very little superior germ plasm would have been lost by discarding the inbred lines in groups 1 and 2, the poorer combining lines in the top cross test. The average yield of all crosses from the two higher combining groups of lines, i. e., group 3 and group 4, was found to be 301 grams per hill. By the use of this value as a criterion for determining the distribution of high and low yielding crosses from the different groups of lines the general summary in Table 3 was obtained.

TABLE 3.—*Distribution of single crosses above and below the mean yield of 301 grams per hill obtained from all single crosses made between high combining inbred lines.*

Groups crossed	Number of single crosses		Average yield of group crosses grams
	Below average	Above average	
Group 1 x group 1 and 2.....	6	0	154
Group 1 x group 3 and 4.....	18	3	253
Group 2 x group 3 and 4.....	7	0	245
Group 3 x group 3..........	4	6	315
Group 4 x group 3 and 4.....	5	6	285

Of the 15 single crosses whose yields exceeded the average from the high combining lines in groups 3 and 4, only 3 were produced from low combining lines and 12 from the better combining lines. These results, together with the correlation coefficients given in Table 1, tend to show that the top cross test as a means of discarding the poor combining lines may be used without a serious loss of high yielding hybrids. It should be recognized, however, that the low combining lines do occasionally produce high-yielding hybrids—particularly when crossed with high-combining inbred lines.

RELATION BETWEEN TOP CROSSES MADE TO PARENTAL VARIETY, TO AN UNRELATED VARIETY, AND TO AN UNRELATED INBRED LINE

The relationship between the yields of the inbred lines in several top crosses determined by means of correlations between the different crosses and correlations between yields at the two locations is given in Table 4.

While several of the correlation coefficients are significant, they are rather low, on the average. Correlations of .2798 and .1761 were obtained, respectively, for yields of top crosses of Golden Bantam at University Farm and Le Sueur and Del Maiz at University Farm and Le Sueur. It should be remembered that three replications for each cross were used at University Farm while only two were used at Le Sueur.

The correlation between yielding ability in all trials at University Farm with all trials at Le Sueur gives an opportunity to compare

TABLE 4.—*Relation between yield of top crosses made with inbred lines of Golden Bantam to the parental variety, to unrelated Del Maiz, and to Del Maiz inbred culture 1 in trials made at University Farm and Le Sueur, Minn.*

Yield of top crosses correlated	Location of test	Correlation coefficient
Golden Bantam with Del Maiz...	University Farm	.3009
Golden Bantam with Del Maiz...	Le Sueur	.3541
Average Golden Bantam with average Del Maiz............	University Farm and Le Sueur	.4214
Golden Bantam with culture 1...	Le Sueur	.2019
Del Maiz with culture 1........	Le Sueur	.0110
Golden Bantam...............	University Farm and Le Sueur	.2798
Del Maiz.....................	University Farm and Le Sueur	.1761
All trials at University Farm with all trials at Le Sueur*........	———	.3633
Significant r (P = .05).........	———	.3246

*Crosses with culture 1 omitted.

the combining ability of inbred lines in two top cross studies (six plats in all) at University Farm with that at Le Sueur (four plats in all). This coefficient was .3633 while significant r is .3246. The yields of Golden Bantam and Del Maiz top crosses at University Farm and Le Sueur were correlated to the extent of only .3009 and .3541, respectively, while combining the top cross yields of the two varieties at University Farm and Le Sueur gave a coefficient of .4214. These results indicate that too few replications were used in these studies to make it possible to draw accurate conclusions regarding the comparative desirability of Golden Bantam and Del Maiz as tests of combining ability of inbred lines of Golden Bantam. Del Maiz culture 1 was selected because it gave desirable crosses for canning purposes. This single inbred line proved very unsatisfactory to test the combining ability of these inbred lines.

The results of these studies indicate that rather careful field trials are needed to determine combining ability. If it is desired to obtain this information in a single season, tests should be made in several localities and sufficient replications, many more than in this study, should be made to insure accurate results.

CHARACTERS OF INBRED LINES RELATED TO TOP CROSS YIELDS

The inbred lines were grown in two separate series of randomized blocks and data were taken on various characters. From an analysis of variance the inbred lines were found to be significantly different in the following seven characters: Yield, ear length, number of suckers, stalk diameter, pulling resistance, leaf area, and plant height. Simple product moment correlation coefficients were computed to determine the relationship between these characters in inbred lines and the combining ability of inbred lines in top crosses.

The data from this study, given in Table 5, show that in the simple correlations stalk diameter and leaf area both show a positive and significant relationship to combining ability of the inbred lines. Ear

length and plant height show a slight positive relation to the top cross yield and number of suckers on the inbred plants a slight negative relation to yield of the top cross. The yield of the inbred lines and their pulling resistance show very little relationship to the yield of the top cross.

TABLE 5.—*Relation between characters of the inbred lines (2–8) and yield of the inbred lines in top crosses (1) as measured by simple and partial correlation coefficients.*

Characters of the inbred lines	Simple correlation coefficients	Partial correlations	
		Characters correlated	Correlation coefficients
Yield (2)............	—.0170	r12.345678	.1946
Ear length (3)........	.2770	r13.245678	.4483
No. of suckers (4).....	—.2619	r14.235678	—.4648
Stalk diameter (5).....	.3781	r15.234678	.4461
Pulling resistance (6)...	—.1070	r16.234578	—.0883
Leaf area (7).........	.3964	r17.234568	.1048
Plant height (8).......	.2791	r18.234567	.0194
Significant r (P = .05).	.3165	———	.3444

In the partial correlation study, the relation between the top cross yield and each of the seven characters of the inbred lines was determined by holding constant all of the other six inbred characters. The partial correlations also give in Table 5 show that ear length and stalk diameter of the inbreds are significantly and positively related to the combining ability of the inbred lines measured by their top cross yields. The number of suckers per plant while nearly significant in the simple correlations is significant and negatively associated with the top cross yield in the partial correlations. Average number of suckers was studied in the 55 single crosses discussed previously and a correlation coefficient computed between yield of F_1 crosses and number of suckers. The coefficient obtained, .0035, shows no association. These results in eight-rowed Golden Bantam crosses are different than those reported by Jones, *et al.*[4] On the basis of this coefficient the degree of suckering in inbred lines and the hybrids between them is not an important factor in determining yielding ability. The relation between the yield of the inbreds and the top cross yields is somewhat greater than that found in the simple correlation but considerably below the 5% point in significance. Pulling resistance, leaf area, and plant height show only a very small relation to the top cross yield as measured by the partial correlations.

In general, none of the characters studied shows a striking relation to the top cross yield. In fact, the multiple correlation between the the top cross yield and all seven inbred characters of .4653 strongly suggests that a large part of the characters that determine combining ability of the inbred lines have not been accounted for in this study.

[4]JONES, D. F., SINGLETON, W. R., and CURTIS, L. C. The correlation between tillering and productiveness in sweet corn crosses. Jour. Amer. Soc. Agron., 27:138–141. 1935.

This may be due to the relative inaccuracy of the data on inbred lines when only two replications were grown.

SUMMARY

In a study of the combining ability of inbred lines of Golden Bantam sweet corn made at University Farm, St. Paul, Minn., 39 inbred lines were top crossed to the parental variety, to an unrelated variety of Del Maiz sweet corn, and to a Del Maiz inbred line. The inbred lines were also grown and measurements were made of several of their characters, including yield. Eleven of the inbred lines used in the top cross study were crossed in all possible combinations to produce 55 single crosses.

The study of the relation between top cross yields and single cross yields between 11 inbred lines shows that inbred lines that give high yields in top crosses are more likely to produce the best single crosses than the inbred lines that give low yield in top crosses. A few good single crosses were obtained between lines that gave high x low yield in top crosses. In a comparison between the average top cross yield of the two parental lines and the single cross between them and in a comparison between the average yield of the two parental lines in nine single crosses and the single cross between them, fairly high correlation coefficients were obtained (r .4748 and r .6991). The difference between these two coefficients is not significant and suggests that the combining ability of inbred lines determined by top crosses and by several tester lines are of nearly equal value in isolating the best combining lines.

A study was made to determine the relationship between the yields of top crosses to the parental variety, to an unrelated variety, and to an unrelated inbred line. The trials were conducted at two locations in the state. Although the correlation between the top cross yields to the parental variety and to unrelated varieties was low, the correlation between the same crosses at the two locations was also low. These results indicate that too few replications were used in this study to draw accurate conclusions on the comparative desirability of the related and unrelated varieties as a test of combining ability of inbred lines. These results also suggest the need for many replications, preferably at several locations, to determine accurately in a single year the combining ability of inbred lines by the use of the top cross test.

In a study of the relationship between characters of the inbred lines and the yield of the lines in top crosses made by means of simple and partial correlations, a few significant but not very high correlations were obtained. Ear length and stalk diameter of the inbred lines tend to be positively associated with top cross yields and number of suckers per plant negatively associated with top cross yields. The yield of the inbred lines was not significantly associated with combining ability in top crosses either in simple or partial correlations.

NOTES

A NURSERY THRESHER FOR SORGHUM HEADS

A NURSERY thresher particularly adapted to threshing individual heads of sorghum has been constructed at the U. S. Dry Land Field Station, Lawton, Okla. Two views of it are shown in Fig. 1. Approximately 2,000 individual heads have been threshed successfully in the past two seasons. Two men can thresh, clean, bag, and label 500 individual heads in 8 hours. The thresher also has been used for nursery rows of wheat and bulk lots of sorghum. It is relatively inexpensive and so simple that any good mechanic can build it.

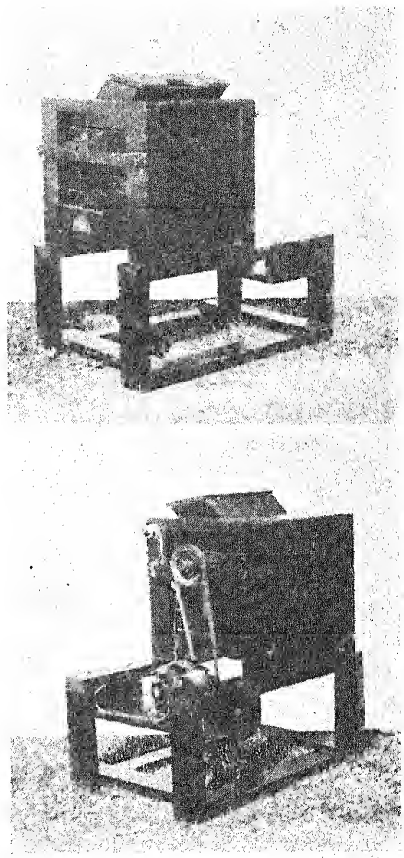

FIG. 1.—A new nursery thresher for sorghum heads.

The thresher is of a box type, designed for self-cleaning, by eliminating projections where grain might lodge and by providing for all material to drop into the grain drawer. The inside is lined with tin that forms a funnel leading to a grain drawer at the bottom. The bottom of the funnel, 6 x 8 inches, is large enough to avoid clogging. The grain drawer is 12 x 8 inches and 4 inches deep.

The thresher frame and base are built of 2 x 4 inch lumber. The sides of the box are 1 x 3 inch tongue and groove boards. The outside dimensions of the frame are 21 inches x 17 inches, and 19 inches high. The feeding chute extends above the top of the box 1½ inches at the front and 2½ inches at the rear. It sits at approximately a 45-degree angle to permit easy insertion of the heads. A hinged lid on the top of the chute with a small notch in the front for the sorghum stem is closed to prevent loss of grain while the head is being threshed.

The cylinder was made from a block of oak 10 inches long that was bored lengthwise and a 7/8-inch steel shaft inserted and secured. The oak cylinder was then turned on a lathe to a diameter of 4 inches. A large metal washer was fastened with screws to each end of the cylinder to prevent splitting of the wood.

The cylinder teeth were made from ¼ inch lag screws 2¼ inches long. Holes 3/16 inch in diameter and 1 inch deep were bored in the cylinder. A small quantity of powdered resin to help hold the screws was poured into each hole. After the screws were in place the heads were cut off with bolt cutters, leaving teeth about 1 inch in length. The teeth were placed 2 inches apart in rows lengthwise of the cylinder and the rows were ½ inch apart. The teeth, in alternate rows, were offset 1 inch to center them in the spaces between the teeth in adjacent rows. There were 24 rows of teeth, with 5 teeth to the row.

The shaft ran in bearings bolted on the frame work of the thresher. The inside width of the thresher, 12 inches, allows a 1-inch clearance at each end of the 10-inch length cylinder to avoid clogging.

The concave was made of a 2 x 8 inch piece of oak on which a concave surface was chiseled. The concave was placed about 1¼ inches from the cylinder so that the ends of the two sets of teeth overlapped about 3/8 inch and was closely fitted and securely fastened to the sides of the thresher to prevent the lodging of grain. The spacing and arrangement of the 45 concave teeth was the same as those on the cylinder.

The thresher is mounted crosswise on a base 14¼ inches high, 33 inches long, and 21 inches wide. An electric motor is mounted on the base at the side of the thresher. The entire unit, weighing 130 pounds, can be moved without disturbing the belt adjustment. The thresher can be operated by a ¼ to ½ horse-power motor, at a speed of about 1,000 R.P.M.

In threshing, the sorghum head is fed into the cylinder gradually and then withdrawn. The grain and chaff fall into the drawer, are screened through ¼ inch hardware cloth to remove the larger particles, and then poured in front of an electric fan to blow out the chaff. Recleaning seldom is necessary.

For convenient handling of the sorghum heads the stems should be at least 8 inches long.—R. O. SNELLING, *Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, Lawton, Okla.*

CYTOLOGY OF CEREALS

THE attention of agronomists, and especially plant breeders, is called to a review of literature pertaining to the cytology of the cereals, including wheat, rye, barley, and oats, made by Hannah C. Aase in BOTANICAL REVIEW, 1 : 467–496, 1935.

A comprehensive review is made of 125 articles most of which have been published since the author's original paper (Research Studies, State Coll. Wash., 2 : 3–60. 1930). A general summary table of chromosome conjugations in F_1 of cereal hybrids is given based on more than 300 crosses, involving more than 150 different species combinations.

Phylogenetic relationships are suggested in a diagram showing allopolyploidy in wheat.—A. M. SCHLEHUBER, *State College of Washington, Pullman, Wash.*

A SPECIAL SLIDE RULE FOR RAPID CALCULATION OF TIME FOR THE WHEAT MEAL FERMENTATION TIME TEST

CONSIDERABLE time is spent in the usual method of calculating the number of minutes that elapse between any two periods of the day. This task becomes very tedious and time consuming, especially when the "time" must be calculated on some 150 or 200 individual fermentation time tests which are carried out daily in connection with quality studies in the wheat breeding program at the Purdue University Experiment Station. Errors can easily be made and often overlooked since it is very easy to add or omit 60 minutes from the total. As a result, the writers were interested in simplifying the calculating of "time" and yet secure the results with speed and accuracy. Calculating tables were found to be too large and clumsy. Since slide rules are used more and more in simplifying calculations, it seemed that special scales might be developed and mounted on a slide rule, and thus the "time" rapidly calculated. Therefore, two special scales ("A" and "B") were developed and mounted on a slide rule as shown in Fig. 1.

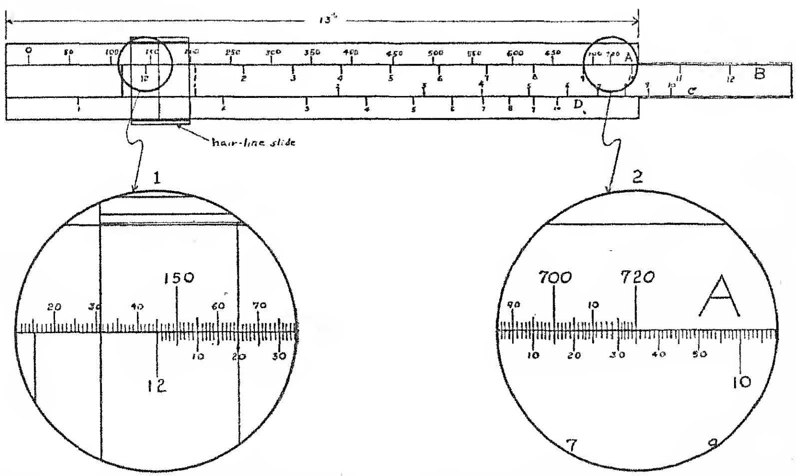

FIG. 1.—A special slide rule used in calculating the total number of minutes between any two periods of the day.

On scale "A" the minutes for a 12-hour period are summed up at 10-minute intervals up to 720 minutes. Scale "B" indicates a linear arrangement of the hours and minutes prevalent during a 12-hour day as ordinarily given on the face of a clock. By means of these two scales, results can be obtained in a few seconds which would require minutes by the usual method.

The following example will illustrate the use of the special slide rule. Suppose one wished to determine the total number of minutes between 9:35 a. m. and 12:20 p. m. Move the slide to the right so that 9:35 on scale "B" is at the right end of scale "A" or at 720,

as shown in Fig. 1. Set the runner so that the hair line is exactly at 12:20 p. m. (scale "B"). The answer, 165 minutes, is obtained at the intersection of the hair line on scale "A". In much the same way the total number of minutes can be determined between any two periods within a 12-hour day.

The regular "C" and "D" scales, used in multiplication and division with standard slide rules, are also included in the above special rule.—W. W. WORZELLA and C. B. JUDAY, *Purdue University Agricultural Experiment Station, Lafayette, Indiana.*

ERRATUM

ON page 72, line 2, of the January, 1936, number of this JOURNAL, in an article on "Cotton Varieties Recognized as Standard Commercial Varieties", substitute the name of E. F. Cauthen for B. C. Rhyne. On page 76 of the same article, second line from the bottom, the sentence reading, "L. L. Ligon, cotton breeder for the Oklahoma Experiment Station, made the original selection and has continued plant selection in the variety each year since 1914", should read, "Glen Briggs, then cotton breeder for the Oklahoma Experiment Station, made the original selection. L. L. Ligon has continued plant selection in the variety since 1925."

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THE EFFECT OF CORN SMUT ON THE YIELD OF GRAIN IN THE SAN JOAQUIN VALLEY OF CALIFORNIA[1]

FRANCIS L. SMITH[2]

CALIFORNIA'S corn crop is grown for two purposes, green table corn and grain corn. Roughly, a little over half of the corn acreage is utilized as a grain crop. In 1933, there were 100,000 acres of corn in California, of which 53,000 was grain corn, producing 1,696,000 bushels (13).[3] According to the 1935 census,[4] there were 59,716 acres of corn in California, 38,450 acres, producing 1,429,093 bushels, being grown for grain.

Grain corn in California is largely used as chicken feed. About 4,931,000 bushels were imported into California from abroad in 1935.[5] Annually some 250,000 to 400,000 bushels are shipped in from other states. We therefore produce less than one-fourth of the corn used in the state.

Most of the state's grain crop is grown in the deltas of the San Joaquin and Sacramento rivers. The 1935 census reported San Joaquin County's grain corn as 21,221 acres, 952,820 bushels, or approximately two-thirds of the state's production.

Each year growers in these areas suffer some losses from corn smut, *Ustilago zeae* (Beckm.) Ung. In 1935 an effort was made to measure the loss that could be attributed to this disease. The variety generally grown throughout the delta region is known locally as King Philip, or more accurately, King Philip Hybrid. This is not to be confused with King Philip, an 8-rowed, red-grained flint corn. This variety was developed about 1900 from a field cross between Reid's Yellow Dent and King Philip, followed by a number of years selection by W. C. Sheldon, a farmer near Elk Grove, California. The grain is not a typical flint nor is it a dent, but is somewhat intermediate in

[1]Contribution from the Division of Agronomy, University of California, Berkeley, Calif. Received for publication January 16, 1936.
[2]Junior Agronomist.
[3]Figures in parenthesis refer to "Literature Cited," p. 265.
[4]Department of Commerce, Bureau of Census. Preliminary report of Farm Census for California. Released Jan. 2, 1936.
[5]Estimates furnished by Dallas W. Smythe, Assistant in Agricultural Extension and Associate on the Giannini Foundation, California Agricultural Experiment Station.

Jorgensen (9), working in Ohio, classified the plants by location of infection but did not report any size differences of smut galls. In selfed lines, infections below the ear gave a decrease of 42%, while a 16% decrease was observed from infections above the ear in selfed lines. Ear infections reduced yield 55%. In F_1 crosses below-ear infections reduced yields 24%, above-ear infections 38%, and ear infections 74%. Only a few comparisons were made on tassel infections and the results were inconclusive. In the selfed lines, the average reduction due to all smut infections was 39% and in the F_1 crosses 50%.

MATERIALS AND METHODS

This study was made in a commercial field of King Philip Hybrid grown about 14 miles west of Stockton on Roberts Island. The land is peat soil from reclaimed tule marshes in the delta of the San Joaquin River.

In order to measure the prevalence of the disease, five counts of 500 plants each were made at random in the field. The sizes and locations of galls on each infected plant were recorded. In each sample the plants were counted consecutively in a single row. The results are summarized in Tables 1, 2, and 3.

Since most of the infections were below-ear, on-ear, and multiple galls only these classes were harvested for yield measurements. No attempt was made to measure losses due to smut on the base, above the ear, or on the tassel because their prevalence was of minor significance.

The ears harvested for yield comparisons were taken in the same field that the counts were made. Three general groups were harvested, with galls below the ear, on the ear, and multiple galls. The sizes of the smut galls were classed the same as by the Minnesota workers (6, 7, 8), small galls being those less than 2 inches, medium galls from 2 to 4 inches, and large galls being over 4 inches in diameter. Ears were harvested from smutted and adjacent nonsmutted plants. Each pair was given the same number. The ears were shelled and the yields were expressed as grams of shelled corn. The results were analyzed by Student's method.

RESULTS

The results of the plant counts are presented in Tables 1, 2, and 3. In Table 1 the counts of single galls are shown, while in Tables 2 and 3 the counts of multiple galls are presented, classified by size in Table 2 and by location in Table 3. There were 435 smutted plants in a total of 2,500 plants, or 17.4%. There were 341 plants with single-gall infections, or 13.64%, and 94 plants with multiple-gall infections, or 3.76%.

In Table 4 are presented the results of the yields from smutted and nonsmutted plants. The number of comparisons in each case is not large, but most of the differences are statistically significant. Odds were calculated from Miles (10) tables which were derived from Student's tables. In cases where N was more than 20 the method outlined by Student (11) was used.

BARRENNESS CAUSED BY SMUT

Large galls caused 35% barren stalks when infection was below the ear and 52% when on the ear. Two or more large galls cause[illegible] 100% barren stalks. A large and medium gall caused 60% barr[illegible] stalks. No barren plants were found with medium galls below the e[illegible]

TABLE 1.—*Counts of single-gall infections of corn smut on Roberts Island, Nov. 20, 1935, each count representing a sample of 500 plants taken consecutively in a single row.*

Count No.	Base			Below ear			Ear			Above ear			Tassel			Leaf	Total in size class			Grand total
	S*	M	L	S	M	L	S	M	L	S	M	L	S	M	L	S	S	M	L	
1	1	—	—	21	16	3	2	16	9	1	—	—	1	—	1	1	27	32	13	72
2	—	1	—	14	6	1	2	5	9	—	2	1	—	—	1	—	16	14	12	42
3	2	2	—	19	13	1	10	12	17	—	—	—	—	—	—	2	33	27	18	78
4	—	—	—	29	19	3	5	13	9	1	—	—	—	2	—	—	35	34	12	81
5	—	1	1	21	13	3	9	8	8	1	1	—	—	—	—	2	33	23	12	68
Total in each class	3	4	1	104	67	11	28	54	52	3	3	1	1	2	2	5	144	130	67	341
Total at each location	8			182			134			7			5			5	341			341

*S = Small, diameter less than 2 inches; M = Medium, diameter 2 to 4 inches; and L = Large, diameter over 4 inches.

TABLE 2.—*Counts of multiple-gall infections of corn smut on Roberts Island, Nov. 20, 1935, each count representing a sample of 500 plants taken consecutively in a single row and classified by size.**

Count No.	SS	SSS+	SM	SM+	SL	MM	MM+	ML	ML+	LL	LL+	Total
1	2	4	8	—	1	4	—	4	—	1	2	26
2	2	—	3	—	—	—	3	1	2	2	3	16
3	—	1	1	1	1	6	1	1	2	2	—	16
4	1	—	8	1	3	8	1	1	1	3	2	29
5	—	1	2	—	1	—	—	—	3	—	—	7
Total in each class	5	6	22	2	6	18	5	7	8	8	7	94

*S = Small, diameter less than 2 inches; M = Medium, diameter 2 to 4 inches; L = Large, diameter over 4 inches; SS = 2 small galls; SSS+ = 3 or more small galls; SM = 1 medium and 1 small gall; and SM+ = 1 medium and 1 or more small galls.

TABLE 3.—*Counts of multiple-gall infections of corn smut on Roberts Island, Nov. 20, 1935, each count representing a sample of 500 plants taken consecutively in a single row and classified by location.**

Count No.	BE	BE-E	BE-AE	BE-E-AE	E	Total
1	14	8	2	—	2	26
2	6	9	—	—	1	16
3	7	5	—	—	4	16
4	15	12	1	1	—	29
5	4	3	—	—	—	7
Total	46	37	3	1	7	94

*BE = Below ear; E = ear; and AE = Above ear.

and only 4% when on the ear. Two multiple galls of medium size did not result in barren stalks. Barren stalks with small galls were not found except where there were three or more. Thus, there is a direct relation of barrenness and size of smut galls. This is in agreement with results obtained by other workers (8).

TABLE 4.—*Effect of size and location of smut galls on yield of shelled grain in King Philip Hybrid, 1935.*

Size of gall*	Number of comparisons	Average loss on smutted plants in grams of shelled grain per plant	Standard error	Percentage reduction	Odds	Number of comparisons in which smutted plants outyielded nonsmutted	Number of smutted plants barren	Percentage of smutted plants barren
				Below Ear				
S	37	12.06	13.11	6.46	4.3:1	16	0	0
M	45	14.37	10.39	7.34	10.3:1	19	0	0
L	17	78.52	22.67	40.53	609:1	3	6	35
				On Ear				
S	18	41.92	12.83	23.38	401:1	2	0	0
M	25	74.62	14.33	40.59	>20000:1	3	1	4
L	23	139.43	14.75	81.67	>20000:1	1	12	52
				Multiple Galls Below Ear				
SS	9	26.20	23.26	12.26	6.0:1	3	0	0
SSS+	4	90.65	33.89	44.28	25.4:1	0	1	25
MS	7	67.13	36.27	37.52	16.6:1	2	0	0
MM or MSS	7	93.43	24.27	48.13	235:1	0	0	0
ML or LSS	5	130.64	42.98	73.19	51:1	0	3	60
LL	2	212.05	3.62	100.00	363:1	0	2	100
				Below Ear and On Ear, All Sizes				
	16	108.66	22.99	57.68	9999:1	2	5	31
				Below Ear and Above Ear, All Sizes				
	5	124.18	27.76	80.75	180:1	0	2	40
				All Locations				
SS	10	37.40	23.63	18.15	12.4:1	3	1	10
SSS+	6	79.33	17.91	41.71	292:1	0	1	17
MS	13	58.92	22.13	33.98	96:1	3	3	23
MM or MSS	4	93.67	19.42	43.04	117:1	0	0	0
MMM+	10	120.02	25.54	63.94	1666:1	1	1	10
ML or LSS	8	135.06	26.52	76.87	1428:1	0	3	37
LL+	4	155.35	25.76	100.00	218:1	0	4	100

*See Tables 1 and 2 for meaning of symbols.

EFFECT OF LOCATION OF SMUT GALLS

A number of investigators have found that in selfed lines the incidence of attack may be limited to certain areas of the plant (1, 4, 5, 6, 7, 8). From this study it seems that King Philip Hybrid is not susceptible to great smut attack at the base, above the ear, and on the tassel. The five cases of smut on the tassel recorded in Table 3 were all on suckers. From these data it is not possible to compare losses from above-ear and below-ear infections. There is, however, conclusive evidence, presented in Table 5, that smut on the ear causes more loss than similar-sized galls below the ear. The differences are hardly significant for small galls but are highly significant for medium and large ones.

TABLE 5.—*Effect of location of smut galls on yields.*

Size of gall	Loss in grams from galls		Difference in grams	Odds
	On ear	Below ear		
Small	41.92±12.83*	12.06±13.11	29.86±18.35	18.5:1
Medium	74.62±14.33	14.37±10.39	62.25±17.70	4695:1
Large	139.43±14.75	78.52±22.67	60.91±27.05	81.7:1

*Standard error used in all cases.

EFFECT OF SIZE OF SMUT GALLS IN REDUCING YIELDS

From the data presented in Table 4 it is possible to calculate the average losses due to galls of different sizes. When galls are all the same size in multiple-gall infections the reduction in yield can be calculated directly by division. When multiple galls are of different sizes the calculations must be made indirectly. Thus, two small galls below the ear reduce the yield 26.20 grams, or 13.10 grams each, and two medium galls 93.43 grams, or 46.72 grams each. A medium and a small gall should reduce yield 59.82 grams. Actually, the reduction for this combination was 67.13 grams, a difference of 7.31 grams. Thus, the reduction in yield due to each gall size can be calculated by interpolation. For example:

For small galls in an MS combination $13.10+(7.31\times.219)=14.70$.

For medium galls in an MS combination $46.72+(7.31\times.781)=52.43$.

Similarly, medium galls reduce yields 46.72 grams and large galls 92.28 grams. But 92.28 plus 46.72 is 139.00, while the actual loss in ML combinations is 130.64 grams, a difference of 8.36.

Then for medium galls in an ML combination $46.72 - (8.36\times.276) = 44.41$ and for large galls in an ML combination $92.28-(8.36\times.724)=86.23$.

The reductions in yields due to different sizes of galls in various combinations are presented in Table 6. Losses expressed in percentages are based on the average yields of nonsmutted plants used as checks. The average yield of 133 plants was 193.06 grams.

Thus, a gall on the ear reduces yield about twice as much as a similar-sized gall below the ear. The reduction in yield for small- and medium-sized galls is proportional to the number. Medium-sized galls

TABLE 6.—*Effect of size of smut galls in reducing grain yields in King Philip Hybrid corn.*

	Small galls		Medium galls		Large galls	
	Combination*	Loss in grams	Combination*	Loss in grams	Combination*	Loss in grams
Below Ear						
	S	12.06	M	14.37	L	78.52
	SS	13.10	MM	46.72	LL	106.03
	MS	14.70	MS	52.43		
			ML	44.41	ML	89.97
Average............		13.29		39.48		91.51
Percentage reduction		6.88		19.36		47.40
On Ear						
	S	41.92	M	74.62	L	139.43
Percentage reduction		23.38		40.59		81.67

*See Tables 1 and 2 for meaning of symbols.

reduce yields about two to three times as much as small galls and large galls reduce yields about twice as much as medium ones. These results are essentially similar to those obtained by Johnson and Christensen (8) in which small galls below the ear reduced yields 11.6%, medium galls 16.5%, and large galls 41.7%. On the ear small galls reduced yields 21%, medium galls 22%, and large galls 87.4%.

ESTIMATION OF LOSSES IN THE FIELD

From the data in Table 4 it is now possible to estimate the losses sustained in the field as shown by the sample counts. These estimations are presented in Table 7.

The estimated values of losses from smut galls of different sizes and locations are taken from Table 4. Losses due to below-ear infections were taken from the calculations made in Table 6. Since there are no data available on losses due to above-ear infections, the same values as below-ear infections were used. This is probably not justifiable according to results obtained by workers at Minnesota (6, 7, 8) and Ohio (9), but the number of affected plants is so small that a change in the value would not materially affect the total. The same holds true for smutted tassels. In cases of multiple galls the estimates are made as closely as the data in Table 4 will permit. Multiple galls at all locations are used as a basis of estimation. Since no measurements were made of some of the multiple combinations, the nearest measurement is used, thus for SM+, SM is used and for ML+, ML is used. These estimates give a total loss due to smut at 6.0% from a field with 17.4% smutted plants. About two-thirds of the loss is from single galls. The greatest loss is from smut on the ear which amounts to 2.8%.

CONCLUSIONS

The data presented in this report, although not as extensive as other reports of a similar character (2, 3, 6, 7, 8, 9), definitely show

TABLE 7.—*Estimation of losses in the field due to smut from a random sample of 2,500 plants.*

Location of gall	Size of gall*	Number of plants	Estimated loss per plant %	Loss in total yield %	Percentage reduction
Base	S	3	7	0.0084	0.0576
	M	4	19	0.0304	
	L	1	47	0.0188	
Below ear	S	104	7	0.2912	1.0072
	M	67	19	0.5092	
	L	11	47	0.2068	
Ear	S	28	23	0.2576	2.8488
	M	54	41	0.8856	
	L	52	82	1.7056	
Above ear	S	3	7	0.0084	0.0500
	M	3	19	0.0228	
	L	1	47	0.0188	
Tassel	S	1	7	0.0028	0.0556
	M	2	19	0.0152	
	L	2	47	0.0376	
Leaf	S	5	7	0.0014	0.0014
Total single galls		341			4.0206
Multiple galls, all locations	SS	5	18	0.0360	
	SSS+	6	42	0.1008	
	SM	22	34	0.2992	
	SM+	2	34	0.0272	
	SL	6	43	0.1032	
	MM	18	43	0.3096	
	MM+	5	43	0.0860	
	ML	7	76	0.2128	
	ML+	8	76	0.2432	
	LL	8	99	0.3168	
	LL+	7	100	0.2800	
Total multiple galls		94			2.0148
Total					6.0354

*See Tables 1 and 2 for meaning of symbols.

that corn smut causes considerable reductions in grain yields in California. In a corn breeding program, of which this is a part, we are attempting to reduce losses by breeding methods. This task is not altogether hopeless in spite of the marked variance of pathogenicity of the forms of the smut organism, for a number of workers have noted selfed lines which are constant in their reaction. Christensen and Johnson (1) and Immer and Christensen (7) have shown that selfed lines react similarly when subjected to epidemics of smut obtained from several sources.

SUMMARY

Grain from 220 pairs of smutted and adjacent nonsmutted plants was weighed. Analyses of differences were made by Student's method.

Losses from smut infection on the ear and below the ear were calculated for small, medium, and large galls. Losses due to multiple galls of a number of different combinations were calculated. Losses due to smut below the ear are estimated to be 7% for small, 19% for medium, and 47% for large galls. Ear infections gave greater losses, 23% for small, 41% for medium, and 82% for large galls.

The percentage of barren stalks increased with the amount of smut. In stalks with large galls on the ear, 52% were barren, while 35% were barren when large galls occurred below the ear. Single small galls produced no barren stalks, neither did medium galls below the ear, but medium galls on the ear caused 4% barrenness. Multiple small and medium galls caused an increase in the percentage of barren stalks. Two or more large galls produced 100% barren stalks.

The estimated loss in yield in the field having 17.4% smutted plants was 6.0%.

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CAN DIFFERENT DEGREES OF BUNT RESISTANCE BE RECOGNIZED IN F_2 PLANTS?[1]

A. M. SCHLEHUBER[2]

IN studies on the genetics of smut resistance some controversy exists as to the most logical method of classification of the smutted plants. It is recognized here, as in other genetic studies, that the plant should be considered as the unit. However, the expression of unity apparently is not well understood. Briggs (1)[3] in 1926 criticized the methods of Gaines (2) in 1923 in which the plants were grouped in three different classes, *viz.*, bunt-free, all bunted, and partly bunted. It was thought by Briggs that this method merely gave a satisfactory quantitative measure of resistance but did not maintain the plant as a unit. Briggs' method consists of dividing the plants into two classes, bunt-free and bunted. Gaines counted the good and bunted heads on the partly bunted plants, giving credit for the wheat produced in computing percentages of bunt.

Smith (4) divided the plants into five bunt-percentage groups for greater ease in counting than was possible by Gaines' method, although the end result was practically the same. He presented data which seem to indicate that genetic differences may be concealed when plants showing various degrees of smutting are placed in one group. One of Smith's tables is reproduced here as Table 1.

It can be noted in Table 1 that the number of bunt-free plants in the two varieties is approximately the same, whereas the distribution is very different. In this example, if the percentage of bunt is based on two groups, bunt-free and bunted, the percentage of bunt in the two varieties is approximately the same, 87% for Hybrid 128 and 86% for Martin; whereas it is approximately double if based on the degree of smutting, 83% for Hybrid 128 and 39% for Martin. Smith states, "It would be conceded that these differences between varieties are due to differences in reaction." Naturally, similar differences would be expected between hybrids.

MATERIALS AND METHODS

Plants which showed various degrees of smutting were selected from an Oro x Hybrid 128 F_2 population grown in the cereal nursery at the State College of Washington, Pullman, Wash., in 1932. The F_2 seed had been inoculated with a composite mixture of physiologic bunt forms. The plants were grouped according to Smith's classification as smut-free and 20, 50, 80, or 100% smut. All the seed from the first four groups was saved and their identity maintained. Bunt collected

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[3]Reference by number is to "Literature Cited," p. 270.

TABLE 1.—*Distribution of plants among the five bunt-percentage groups and percentage of bunt in each row of duplicate rows of Hybrid 128 and Martin wheat inoculated with physiologic form T-2 and grown in 1930. (After Smith, 4, page 93.)*

Row No.	Number of plants in bunt-percentage group indicated					Total No. of plants	Percentag of bunt in row
	0	20	50	80	100		
Hybrid 128							
1	5	0	1	2	20	28	79
291	3	1	0	3	26	33	87
Martin							
5	3	7	5	6	0	21	41
299	4	12	8	4	1	29	37*

*Percentage of bunt in row 299 = $\frac{(20x12)+(50x8)+(80x4)+(100x1)}{29}$ = 37.

Briggs' method: $\frac{12+8+4+1}{29}$ = 86% smut.

from the totally bunted plants was used to inoculate the F_3 seed. The seed from each F_2 plant was planted in a rod row of 75 seeds each. The rows of each group were distributed uniformly throughout the field. Sufficient check rows of Hybrid 128 were included to test the viability of the inoculum.

At harvest time the plants from each row were again classified into the smut groups and the percentages of smut computed.

On account of the severe winter in 1933 many of the plants winter-killed and for this reason it was felt that the results obtained that year were rather inconclusive. Consequently, a similar study was carried on the following year. This time a White Odessa (Wash. 2308) x Turkey-Florence (Wash. 2471) F_2 population was used. The methods used were the same as those for the preceding year with the exception that, in addition to the check rows of Hybrid 128, check rows of White Odessa and Turkey-Florence were planted.

RESULTS

The average percentage of smut of the two F_3 families is shown in Table 2.

TABLE 2.—*Smut reaction of F_2 and F_3 families of two winter wheat crosses when inoculated with a composite mixture of physiologic forms of bunt.*

Cross	F_2 smut classes											
	Smut-free			20%			50%			80%		
	Av. % smut in F_3	Range	No. rows	Av. % smut in F_3	Range	No. rows	Av. % smut in F_3	Range	No. rows	Av. % smut in F_3	Range	No. rows
Oro x Hyb. 128..	8	0–70	66	20	0–100	22	30	9–82	23	26	0–86	18
Wh. Od. x T-F...	47	11–89	39	59	12– 94	41	69	45–96	40	75	46–98	30

As indicated in Table 2 there was an average of 8% of smut in the F_3 rows grown from seed of F_2 smut-free plants of Oro x Hybrid 128. The range in percentage of smut indicates that a number of the F_2 plants escaped infection. In some cases the presence of smut in the F_3 families may have been due to the action of dominant resistant genes in the F_2. The amount of smut produced in the F_3 from the 80% smutted F_2 plants is low.

The differential effect of winterkilling on smut-susceptible and non-susceptible varieties is clearly demonstrated by the results of a smut and winterhardiness experiment carried on the same year by Holton and Schlehuber (3). They found that the percentage stand varied considerably but was lowest in Hybrid 128, the most susceptible variety, and highest in Jenkin-Ridit (Wash. 2807), the most resistant variety used in the experiment. They also found that the average percentage of smut for two series in Hybrid 128 was 80 for those rows grown from seed that was inoculated with only a trace of smut and 65 for those which received a heavy inoculation. Considering the fact that the fall stand was the same in both cases this would seem to indicate that the most smut-susceptible plants were the most easily winterkilled. This fact may possibly explain why the amount of smut is very much reduced in the 80% smutted F_3 families in Oro x Hybrid 128.

The White Odessa x Turkey-Florence F_3 was studied and analyzed in somewhat greater detail than the other cross. Sixteen rows of Turkey-Florence had an average of 30 ± 3.69% smut and a range from 22 to 41%. Sixteen rows of White Odessa had an average of 86 ± 3.04% smut and a range of 77 to 92%. In both cases the deviations do not exceed three times the probable error.

One hundred and fifty F_3 rows were planted which represented an F_2 grouping of 39 smut-free, 41 of 20% smut, 40 of 50% smut, and 30 of 80% smut. The reaction of these F_3 lines is represented in Fig. 1.

Five classes of smut ranges are represented in Fig. 1, *viz.*, class I, 0 to 21% smut, exceeds the resistance of Turkey-Florence; class II, 22 to 41% smut, the range of Turkey-Florence; class III, 42 to 76% smut, the range between the two parents; class IV, 77 to 92% smut, the range of White Odessa; and class V, 93 to 100% smut, exceeds the susceptibility of White Odessa.

Fig. 1 shows that only F_3 families descending from smut-free and 20% smutted F_2 plants are represented in the first two classes, and that there are comparatively more of the smut-free than of the 20% lines. This condition is reversed in the classes representing the higher smut percentages until in class V there are no F_3 families from smut-free F_2 plants. The 20% smut families are represented in every class with a distribution approximating a normal curve, the percentages in classes I to V being: 2.4, 17.0, 65.8, 12.1, and 2.4, respectively.

Another significant comparison is that between the lines descending from the 50 and the 80% smutted F_2 plants. No families from these groups appear in classes I and II. In class III there are 70% of all 50% smutted plants tested and only 46.6% of the 80% group. In class IV, however, there are only 27.5% of the 50% group and 43.3%

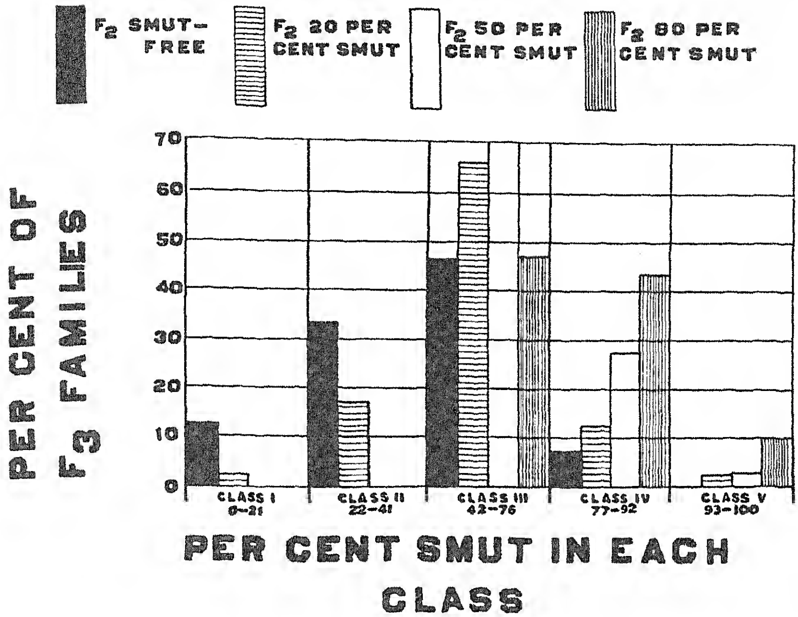

FIG. 1.—Reaction of White Odessa × Turkey-Florence F_3 to a mixture of smuts when selected from smut-free, 20%, 50%, and 80% F_2 plants. The range of Turkey-Florence was 22 to 41% smut and that of White Odessa 77 to 92%. There are three classes of F_3 families different from the parents, one more resistant, one intermediate, and one more susceptible.

of the 80% group. In class V there are twice as many F_3 families from the 80% group as from all the other groups added together.

The segregation of F_3 families from the various F_2 smut groups in class IV apparently presents differences in genetic constitution of the different groups. Here, the percentage of F_3 families descending from each group is as follows: Smut-free group, 7.6; 20% group, 12.1; 50% group, 27.5; and 80% group, 43.3.

The practical application of these facts in a breeding program for smut resistance can be readily illustrated. For instance, when smut-free and 20% smutted F_2 plants are selected from a cross of this type, it is possible to obtain families that are more smut resistant than either parent. If 50% and 80% F_2 plants are selected, it is impossible to obtain families that are even as resistant as the resistant parent. Smut-free F_2 plants produced five times as many resistant F_3 families as the F_2 plants that were 20% smutted.

CONCLUSIONS

Data are presented which show definitely that different degrees of bunt resistance can be recognized in F_2 plants. The data are evaluated from the standpoint of a practical application in a program of breeding for bunt resistance.

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RESISTANCE OF SORGHUM TO STEM BORERS[1]

Tien Sih Hsu[2]

STEM borers are notorious insect pests of common occurrence in North China. There are several species infesting sorghum of which the most important are *Pyrausta nubilalis* and *Diatraea diatraea*. This paper records results of studies of the extent of infestation by stem borers in sorghum in Peiping, China.

REVIEW OF LITERATURE

Marston (5, 6, 8)[3] found that a South American strain of flint corn, Maize Amargo, was highly resistant to the corn borer, *Pyrausta nubilalis* Huebn, since the moths did not lay their eggs on it. It was crossed with various strains of dent corn. The F_1 was quite susceptible, but the F_2 much less so, showing that segregation had occurred. The results indicated a monohybrid segregation.

Sweet corn growers in Michigan found it difficult to market corn due to the fact that practically all ears were infested by the corn borer. However, certain F_3 and F_4 inbred lines from crosses of Golden Bantam with Maize Amargo showed considerable reduction in infestation (7).

Shen and Shen (13) found at Nanking that over a period of 5 years the rice strain 1-3-86 was consistently damaged the least by *Schoenobius incertillus* Wlk, and *Chilo simplex* Bult. One variety, named Ningpo Sen, which was very resistant to the borers, had the ability to produce about 70% more tillers than other varieties of rice.

Sorghum varieties differ very sharply in their ability to resist the chinch bug attack. The exact basis of resistance and susceptibility is unknown, but the structure of the stem, amount of lignified tissue, and arrangement of fibrovascular bundles may be considered as factors of some importance (10, 12).

Painter, Salmon, and Parker (11) supplied evidence to indicate that some varieties of winter wheat, such as Fulhard and Kawvale, possess a high degree of resistance to the Hessian fly, *Phytophyga destructor* Say, that factors for resistance are inherited, and that fly resistance may be combined with other desirable characters. Considerable evidence was given also for the presence of biological strains of the Hessian fly.

An account of aphis immunity of teosinte-corn hybrids was given by Gernert (3). He stated that teosinte was practically immune from attack by corn aphis, *Aphis maidis*, as determined from a trial conducted for 2 years. A cross was made between teosinte and yellow dent corn, and the F_1 progenies were found to be as resistant as the teosinte. It was believed that susceptibility in corn might be correlated with the production of sweet juice.

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[2]Agronomist and Chief of the Division of Agronomy, Kwangsi Agricultural Experiment Station, Linchow, Kwangsi, China. The data were taken when the writer was in charge of sorghum breeding at the Crop Improvement Station, Yenching University, Peiping, China. The writer wishes to express his appreciation to Dr. H. K. Hayes, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, under whose direction the analysis of the data was made and the manuscript was prepared.

[3]Figures in parenthesis refer to "Literature Cited," p. 278.

Chopra (1) found that the indigenous varieties of cocksfoot grass suffered far more severely from the cocksfoot moth, *Glyphipteryx fischeriella* Zell., than those from foreign countries because of the coloration of panicles at the flowering stage. It was noticed at the flowering stage that the indigenous varieties had a steel blue tinge upon the panicles, while the foreign strains were mostly green to pale yellow. The coloration difference has, therefore, some influence in guiding the moth in its choice of plants upon which eggs are laid.

Results obtained by Isely (4) indicate that the boll weevil had a marked preference for cotton plants with green foliage over those with red foliage.

The pH value is important in determining resistance of apple varieties to the woolly aphis. A study made by Monzen (9) shows that the apple variety susceptible to woolly aphis has a pH value of 5.0, whereas in the resistant variety the pH value is 4.4 only. There is another factor for the resistance to woolly aphis, i.e., the amount of sclerenchyma around the circumference of the stem. Staniland (15) classified apple stocks into four groups as follows: The very susceptible group containing 61 to 65% sclerenchyma, the susceptible group containing 66 to 70% sclerenchyma, the resistant group containing 71 to 75% sclerenchyma, and the immune group containing 76 to 80% sclerenchyma.

MATERIALS AND METHODS

Three groups of strains and varieties of sorghum were tested in 1933. Group I consisted of 981 strains with 2 replications, group II of 16 strains with 5 replications, and group III of 76 strains and varieties with 10 replications. In all cases, single-row plats were used. The strains and varieties grown in these groups were obtained from various sorghum-producing regions in North China. In addition, 10 varieties were introduced from the United States.

The number of plants in a row and number of plants infested were determined in the field. The data thus secured were converted into percentage as a common basis for comparison.

For the 1934 planting, selections of strains and varieties that were apparently resistant and susceptible in 1933 were made for the purpose of determining whether resistance was inherited. The method of planting was much the same as that used for rod-row trials of small grains. There were 10 replications.

All strains and varieties which appeared resistant in 1933 were selected for further study. Single 8-foot-row plats were used, each being covered with a tent of cheesecloth 9 feet long and 1½ feet wide. When the crop averaged about 2 feet high, four moths were introduced into each of the tents. After about three weeks, notes on infestation were taken in each row and all infested plants were counted and removed. A second study of controlled infestation was made by placing two newly hatched larvae on each uninfested plant in each tent, the larvae being collected from sorghum seedlings planted in the field.

A wire cage was used for raising moths. A number of infested stalks were placed in the cage and moths were caught and introduced into the experimental tents as soon as they were available. Another method used to raise moths consisted of collecting pupae and large larvae from the infested stalks and dropping them into well-ventilated bottles.

A large cheesecloth tent about 23 feet long, 10 feet wide, and 12 feet high was used for investigations of the host selection of moths. Under this tent 13 apparently resistant strains and varieties were planted together with 5 susceptible ones as well as 6 varieties of sorgo. Eight plants were grown of each strain or variety.

The significance of differences between varieties in regard to the degree of infestation was tested by Fisher's (2) analysis of variance, and the extent of correlation between 1933 and 1934 infestation was studied by means of the correlation coefficient. The possible association between borer injury and plant character differences was studied by means of X^2 for independence.

EXPERIMENTAL RESULTS

BORER INJURY IN 1933

Among 981 strains of sorghum replicated twice, there were 23 with less than 4% infestation and 29 with more than 25%. Sixteen strains grown in another trial with five replications gave borer injury ranging from 3.4 to 16.5%.

Seventy-six strains and varieties were grown in a 10-row trial with results as follows:

	% Borer Injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	more than 20	Total
Number strains and varieties........	11	25	25	10	5	76

These figures show considerable variation in infestation by stem borers in sorghum. An analysis of variance (Table 1) was made to determine whether the differences were significant statistically. The value of F for a comparison of variation between varieties and error was 9.69 (dividing 321.20 by 33.14). According to Snedecor's (14) table, the highly significant value is about 1.08 for 75 degrees of freedom for the greater mean square and 684 degrees of freedom for the smaller mean square. Obviously, the variance for varietal infestation is of very high significance.

TABLE 1.—*Results of analysis of variance in the 10-row trial, 1933.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F
Varieties.........	75	24,089.77	321.20	9.69
Error...........	684	22,670.10	33.14	
Total.........	759	46,759.87	——	

BORER INJURY IN 1934

Selections of strains and varieties of sorghum that were classed as resistant and susceptible were made in 1933 for further test. They were planted in the field in 1934 together with six varieties of sorgo. Results of infestation are summarized as follows:

	% Borer Injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	more than 20	Total
Number strains and varieties........	7	7	8	2	1	25

An analysis of variance was made also to study the significance of differences in borer injury between various strains and varieties.

Either because of poor stand or because of missing rows, five varieties were excluded from the calculation. The results of the analysis of variance are presented in Table 2. When F equals 1.92, it is on the 1% point. Therefore, it is considered that the variance for varieties is much greater than the variance for error.

TABLE 2.—*Results of analysis of variance for the field test, 1934.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares	F
Varieties	19	4,900.08	257.90	6.56
Error	180	7,075.67	39.31	
Total	199	11,975.75	—	

The correlation between percentage of borer infestation in 1933 and 1934 was determined. Only 13 strains and varieties having the same number of replications and grown in both years were used for this study. A correlation coefficient of .72 was obtained for the extent of infestation between 1933 and 1934. According to Table VA (Fisher, 2), r is on the 1% point when its value equals .6835 and there are 11 degrees of freedom. Therefore, the correlation appears rather significant. Too much importance, however, must not be given to a single correlation coefficient where only 13 pairs of variables are available. The results obtained may indicate that there is a fairly high association between 1933 and 1934 so far as borer injury is concerned, and that the extent of infestation seems more or less consistent in a strain or variety. The strains and varieties grown in both years were used also in studying the interaction between years. The results are given in Table 3.

TABLE 3.—*Analyses of variance for percentage of borer infestation 1933, 1934.*

Variation due to	Degrees of freedom	Sum of squares	Mean squares
Varieties	12	14,437.10	1,203.09
Years	1	12.63	12.63
Varieties x years	12	3,362.10	280.18
Error	234	10,587.73	45.25
Total	259	28,399.56	—

The variance for "varieties" and the variance for "interaction of varieties with years" are both significantly greater than that for error, as shown by very high values of F. With 12 degrees of freedom for the larger mean square and 234 degrees of freedom for the smaller mean square, F is on the 1% point at a value of 2.28. The variance in "varieties" compared with error gave an F value of 26.59 and shows the existence of significant differences between strains and varieties in the infestation by stem borers, whereas the variance in "interaction of varieties with years" compared with error gave an F value of 6.19 and reveals the fact that the differences between these varieties in the extent of injury were not constant for the two years.

For the purpose of testing under controlled conditions the varieties that were found least infested in 1933, plantings were made separately

under cheesecloth tents and moths were introduced when the plants averaged about 2 feet in height. It was found that all were infested with the exception of three varieties, A93, A94, and A95, although there were wide differences in the extent of infestation. A few days later two newly hatched larvae were placed on each plant not previously infested. Notes on borer injury were taken at the end of July. The results indicate that without a single exception all varieties were infested both on leaves and stems.

In order to study the host selection of moths, all varieties and strains which were found to be slightly or heavily infested in 1933 were planted under a cheesecloth tent together with six varieties of sorgo. After the plants grew 2 to 5 feet in height, about 50 moths were liberated in the tent. The number of plants infested by stem borers was observed afterwards in each strain or variety. The detailed data are not presented here. Of six varieties of sorgo, four were infested by stem borers. Among 13 sorghum strains and varieties that were slightly infested in 1933, only three of them suffered from borer invasion. On the contrary, two out of five varieties which were heavily injured in 1933 carried no infestation. In other words, on the average, sorgos suffered most from borers, next came the strains and varieties which were heavily infested in 1933 and last the varieties which appeared resistant in 1933. There are, however, several exceptions to this rule. These results tend to show that probably the moths had a greater tendency to lay eggs upon plants of the sorgo and "susceptible" varieties.

ASSOCIATION BETWEEN INFESTATION AND PLANT CHARACTERS

Studies were made in 1933 of the relation between the percentage of borer infestation and color of grains, height of plant, and stiffness of stalks. Table 4 gives a contingency surface for the relation of percentage of infestation and color of grains in the 10-row trial of 1933. A study of the results given in this table leads to the conclusion that varieties with white grains suffered least from the pest and that varieties with pink grains were less infested than those with yellow or red grains.

TABLE 4.—*The frequency distribution of plats according to borer injury and color of grains in the 10-row trial, 1933.*

Color of grains	Percentage of borer injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	More than 20	Total
White	87	16	5	1	1	110
Pink	19	13	13	3	2	50
Yellow	32	36	75	23	44	210
Red	47	79	128	47	59	360
Total	185	144	221	74	106	730

Table 5 gives similar results for borer injury and height of plants. The shorter varieties appear to have less infestation than the varieties of medium height.

TABLE 5.—*The frequency distribution of plats according to borer injury and height of plants in the 10-row trial, 1933.*

Height of plants	Percentage of borer injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	More than 20	Total
Tall	68	51	74	10	7	210
Medium tall	29	32	68	29	42	200
Medium	21	40	71	34	54	220
Medium short	24	4	2	0	0	30
Short	32	11	3	1	3	50
Dwarf	11	6	3	0	0	20
Total	185	144	221	74	106	730

X^2 for independence was calculated to determine the possible association between borer injury and plant characters. In 1933 the results of the 10-row trial were used with the exception of three varieties which showed mixture in one character or another. Table 6 presents the results of calculation.

TABLE 6.—*The X^2 for independence between borer injury and plant characters, 1933.*

Characters studied	X^2	D/F	P
Borer injury and color of grains	230.0111	12	Less than .01
Borer injury and height of plants	205.2667	20	Less than .01
Borer injury and stiffness of stalks	4.4222	4	0.36

From Table 6 it is learned that borer injury is highly associated with color of grains and height of plants. There appears to be no association between stiffness of stalks and borer injury as the value of P obtained is much greater than .05.

Studies were also made in 1934 to determine the extent of association, if any, between borer injury and color of grains, height of plants, and stiffness of stalks. The data for stiffness of stalks were classified into two categories only, stiff and weak. As in 1933 there were five classes for extent of borer infestation. A contingency surface for infestation and stiffness of stalks is given in Table 7. No relation is obvious from a study of the table, and if apparent association is obtained, it may result from the small number of plats classified in the weak class.

TABLE 7.—*The frequency distribution of plats according to borer injury and stiffness of stalks, 1934.*

Stiffness of stalks	Percentage of borer injury					
	0–4.9	5.0–9.9	10.0–14.9	15.0–19.9	More than 20	Total
Stiff	50	26	26	7	14	123
Weak	2	2	10	7	9	30
Total	52	28	36	14	23	153

X^2 for independence was computed also with the data of 1934. Sorgos and three other strains were not included in the study because of lack of information as to plant characters. The results, which are given in Table 8, agree fairly well with those of 1933, except that stiffness of stalks showed no relation with borer injury in the preceding year and had a striking association in 1934.

TABLE 8.—*The X^2 for independence between borer injury and plant characters, 1934.*

Characters studied	X^2	D/F	P
Borer injury and color of grains.....	64.4466	12	Less than .01
Borer injury and height of plants.....	95.7911	20	Less than .01
Borer injury and stiffness of stalks....	26.5669	4	Less than .01

DISCUSSION

From the two years' experimental results it is doubtful if true resistance to stem borer is available in the sorghum varieties tested. Those with low injury probably escaped for various reasons such as differences in height of plant. The few moths introduced into each of the small tents with perhaps no eggs laid on seedlings may account for the fact that A93, A94, and A95 were free from infestation. This can be confirmed by results of the field trial showing that these three varieties were not completely free from borer injury, and also by the results of placing larvae on plants of all varieties in which case every strain or variety tested was severely injured.

Sorgos were heavily infested under controlled conditions, yet suffered little in the field test. This is probably because the dimensions of the tent were rather small as compared with a field, thus making probable the infestation of all varieties under the tent.

It was noticed from field tests that the extent of infestation by stem borers in sorghum varies with varieties. The host selection of moths may be considered as one of the causes for this phenomenon as shown by results obtained under controlled conditions.

The significant association between infestation and height of plants may be explained by the assumption that tall plants present more space to the borer's attack than the short and dwarf plants.

It seems peculiar that color of grains may have some relation with borer injury. It is hardly conceivable that color of grains itself should play a part in this regard. Possibly some other characters associated with white grains may be important factors for borer resistance. The exact explanation must await further study and for this purpose physiological factors, such as the amount and sweetness of plant juice, the pH value of cell sap, or morphological factors, such as the amount and distribution of sclerenchyma, or both, should be investigated.

SUMMARY

1. Grain sorghum is attacked by several species of stem borers, such as *Pyrausta nubilalis*, *Diatraea diatraea*, etc.

2. Data were obtained from the study of infestation in 1,073 strains

and varieties in 1933, indicating that the extent of infestation by stem borers varied with varieties.

3. Further data obtained in 1934 under both field and controlled conditions gave further indication of differences in varietal infestation.

4. Under controlled conditions sorgos as a group were more susceptible to the insect than the nonsaccharine varieties.

5. Host selection of the "laying" moths is a possible cause for the varying degrees of infestation in different varieties of sorghum.

6. The degree of infestation by borers is probably a heritable character as the correlation between 1933 and 1934 infestation was significantly high.

7. Studied by means of X^2 for independence, borer infestation was found to be consistently associated with color of grains and height of plants.

8. White grain varieties showed less infestation by borers than varieties with other grain colors. The reason for this relation is unknown.

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INHERITANCE OF RESISTANCE TO ROOT ROT IN TOBACCO CAUSED BY *THIELAVIA BASICOLA*[1]

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DURING the past several years the West Virginia Agricultural Experiment Station, in cooperation with the Division of Tobacco and Plant Nutrition, Bureau of Plant Industry, U. S. Dept. of Agriculture, has had under way a project to produce by hybridization and selection a strain of Burley tobacco resistant to root rot caused by *Thielavia basicola*. Incidental to this investigation certain data pertaining to inheritance of disease resistance was obtained. The purpose of this paper is to present these data, together with a brief discussion of them.

Studies by Johnson and Hartman (1)[3] and by Johnson (2,3) have shown the importance of various environmental factors in the development of root rot in tobacco as well as the feasibility of breeding tobacco resistant to this disease.

MATERIALS AND METHODS

The parent resistant to root rot used in the present investigation and designated by the number 10 Ba, was derived from seed of hybrid origin obtained from Dr. James Johnson of the Wisconsin Agricultural Experiment Station. The seed obtained from Dr. Johnson was borne on F_4 plants descended from a cross between pure lines of a drooping leaf, resistant Burley and Judy's Pride Standup Burley. The individual plant used as the resistant parent of the crosses reported below was in the F_{12} generation obtained through successive hand pollinations and was of the standup Burley type. The susceptible Burley parent used was Kelly, an individual plant of a variety capable of yielding high-quality tobacco. The progenies resulting from crossing, backcrossing, and subsequent selfing the resistant and susceptible parents were grown in a seedbed known to be free from *Thielavia basicola* and set out in a heavily limed field known to contain this organism from previous crops of tobacco. Infested soil was obtained through the courtesy of Dr. W. D. Valleau of the Kentucky Agricultural Experiment Station. When the plants were set out their roots were dipped into a heavy soil suspension containing the root rot organism.

Each strain was grown in single-row plats replicated four times, with 25 plants per plat. The rows were 3 feet apart and the plants spaced 18 inches along the row. The field on which the plants were grown is located on first bottom along the Ohio River and is mapped as Huntington silt loam. The fertilizer used on the tobacco in 1933 and in 1934 consisted of 400 pounds per acre of a 4-10-6.

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[3]Figures in parentheses refer to "Literature Cited," p. 283.

The parents and the progenies which resulted from selfing the backcross to the susceptible Kelly parent were grown and studied during two years. As an indication of plant infection, height measurements were made. In 1934 measurements were made at three different times during the last half of the growth period.

DATA OBTAINED IN 1933

In Table 1 are shown the frequency distributions of average height in inches of the parents and hybrid progenies grown in 1933 at the Lakin Experiment Farm. Each hybrid strain was grown on quadruplicate plats systematically distributed. The average height for a particular strain is based on approximately 100 plants. Similarly, each single unit in the frequency distribution for the parents represents approximately 100 plants on four systematically distributed plats. The plats occupied by the parental material were distributed throughout the nursery. The height measurements were made during three days, July 12, 14, and 17, before any of the plants had begun to bloom.

TABLE 1.—*Frequency distribution of average height in inches of progenies obtained by selfing backcrosses of the F_1 to the Kelly parent and of the parent plants grown in 1933 at Lakin, W. Va.*

Name	Mid-classes in inches																					
	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5	26.5	27.5	28.5	29.5	30.5	31.5	32.5	Total
10 Ba parent....	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—	2	—	2	1	—	7
Kelly parent....	—	1	—	—	4	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	7
(Kelly x 10 Ba) x Kelly, selfed..	1	1	2	6	5	7	7	12	15	13	10	14	11	10	9	5	2	2	4	—	1	137
(10 Ba x Kelly) x Kelly, selfed..	—	—	—	—	—	—	—	1	1	2	3	1	—	—	2	1	—	1	—	—	—	12

It is apparent from Table 1 that the average heights of the susceptible Kelly parent ranged significantly below those of 10 Ba, the resistant parent. The difference was striking and persisted throughout the whole of the growing period. The distribution of average heights of the 137 strains which resulted from backcrossing F_1 (Kelly x 10 Ba) to Kelly and then selfing was not dissimilar to that of average heights of the 12 strains which resulted from backcrossing the reciprocal F_1 to the same parent and then selfing the immediate descendants from this backcross. Considering both of these distributions there are 42 out of a total of 149 strains which show average heights within the range marked by the Kelly parent. Similarly, there are 48 average heights of strains of hybrid origin which fall within the range of the resistant 10 Ba parent.

DATA OBTAINED IN 1934

The planting in 1934 was a duplicate of that in 1933 except that some of the hybrid strains did not appear because seed of them was not available. The distributions of average heights shown in Table 2 are based on measurements made from July 24 to 27, inclusive, before any of the tobacco was in bloom.

TABLE 2.—*Frequency distributions of average height in inches of progenies obtained by selfing backcrosses of the F_1 to the Kelly parent and of the parent plants grown in 1934 at Lakin, W. Va.*

Name	Mid-classes in inches												
	8	9	10	11	12	13	14	15	16	17	18	19	
10 Ba parent	–	–	–	–	–	–	–	–	–	–	–	1	
Kelly parent	1	–	2	–	–	–	–	–	–	–	–	–	
(Kelly x 10 Ba) x Kelly	–	–	–	–	3	4	8	10	7	12	14	11	
(10 Ba x Kelly) x Kelly	–	–	–	–	–	–	1	–	3	–	1	1	
Name	**Mid-classes in inches**												**Total**
	20	21	22	23	24	25	26	27	28	29	30	31	
10 Ba parent	–	–	–	2	–	1	–	–	1	–	–	–	5
Kelly parent	–	–	–	–	–	–	–	–	–	–	–	–	3
(Kelly x 10 Ba) x Kelly	10	11	8	3	6	3	7	1	2	4	0	1	125
(10 Ba x Kelly) x Kelly	3	1	2	–	–	–	–	–	–	–	–	–	12

The relative distributions for average heights of the parents are similar to those shown in Table 1. There is a distinct difference between the resistant and susceptible parent. The average heights of the strains of hybrid origin are in general similar to those obtained the previous year, but differ in their relation to the distribution shown by the parents in that a relatively large proportion (over one-half) of the average heights fall within the ranges of those for the resistant 10 Ba parent and none of them within the range of those for the susceptible Kelly parent. There were only 12 plats (three groups consisting of four replicates each) of the Kelly parent grown in 1934.

In 1934, as has been stated, three measurements of height of plant were made, the first from July 24 to 27, inclusive; the second from August 8 to 13, inclusive; and the third from September 6 to 10, inclusive. At the time the last measurement was made the percentage of plants not in bloom was determined. Correlation coefficients were computed (Table 3) showing the linear relations between these values for the 125 tobacco strains designated in Table 2 as (Kelly x 10 Ba) x Kelly.

TABLE 3.—*Interrelation of mean heights of tobacco determined at successive growth periods and the relation between the mean height of plant at first period and percentage of plants not in bloom at third period expressed as coefficients of correlation.*

Correlation between	n	r
Mean heights at first and second periods	125	+0.950
Mean heights at first and third periods	125	—0.040
Mean heights at second and third periods	125	+0.028
Mean height at first period and per cent of plants not in bloom at third period	125	—0.689

The significantly high correlation coefficient (+0.950) between the mean heights of the first and second measurements of the 125 strains of tobacco of hybrid origin indicates that the dwarfing effect of the

root rot organism persisted until the middle of August. The coefficient between the mean heights of the first and third measurements, and likewise between the second and third measurement, is sensibly zero. This indicates that the relative differences in mean heights which persisted up until the middle of August were for the most part overcome after that time. The recovery after mid-August may be partly attributed to relatively high soil temperatures during the last two weeks in July. It has been shown (1) that high temperatures impede progress of the root rot disease. No soil temperature records are available, but the average daily maximum temperatures by weeks for July and August during 1934 at Lakin are July 1 to 7, 89.9° F; July 8 to 14, 87.7° F; July 15 to 21, 96.3° F; July 22 to 28, 99.6° F; July 29 to Aug. 4, 87.1° F; Aug. 5 to 11, 89.3° F; Aug. 12 to 18, 87.3° F; Aug. 19 to 25, 83.0° F; and Aug. 26 to 31, 80.7° F.

The high negative correlation ($r = -0.689$) between the mean height at the first measurement and the percentage of plants not in bloom at the time of the third measurement may indicate the extent to which blooming was delayed by root rot infection.

DISCUSSION

There is some objection to using height of plant (3) as an index of susceptibility of tobacco to root infection by *Thielavia basicola*, because it is obvious that there may be additional causative factors operative to bring about dwarfing. It is believed, however, that the height measurements reported here are indicative of infection by the organism causing root rot. The parents, 10 Ba and Kelly, normally are of about the same height and flower at about the same time. The root rot organism *Thielavia basicola* was known to be present and the soil conditions were favorable (1) for a high incidence of the disease caused by the organism. The parents used in the cross showed a striking difference in growth (Fig. 1) in soil infested with root rot. Kelly, which was known to be susceptible, remained stunted throughout the whole of the growing period, but 10 Ba, the resistant parent, showed normal growth with no tendency to become dwarfed.

The first-generation crosses were backcrossed to the Kelly parent and the immediate resultant progeny self-fertilized. If a single main factor difference was operative in controlling inheritance of reaction to *T. basicola*, one would expect about one-half of the strains coming from the above-mentioned selfing to react in a manner similar to one of the parents; if two factor differences were operative, one-fourth of such strains should so react. As a matter of fact, in 1933, somewhat over one-fourth, and in 1934, over one-half of the strains of hybrid origin reacted in a manner similar to that of the resistant 10 Ba parent. The data are too meagre to make it worth while to speculate as to the number of factors concerned, but they do show that reaction to *T. basicola* in tobacco is inherited.

In 1932, the F_1 plants from the cross 10 Ba x Kelly were grown under conditions similar to those which have been described and for the most part were found to be resistant to root rot. This, together with the data presented in Tables 1 and 2, indicates that resistance

FIG. 1.—Kelly, on the right, and 10 Ba parents growing in adjacent rows at the Lakin Experiment Farm in 1932. Kelly, shows the dwarfing effect of root rot, *Thielavia basicola*.

behaves at least as a partial dominant, as has been reported by Johnson (2).

CONCLUSIONS

Resistance of tobacco *Thielavia basicola* is heritable as a dominant or partially dominant characteristic.

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THE INFLUENCE OF THE AWN UPON THE DEVELOPMENT OF THE KERNEL OF WHEAT[1]

C. E. Rosenquist[2]

AWNED varieties of wheat are rapidly replacing the awnless varieties in the United States. They have been generally reported to be better adapted than the available awnless varieties and to have produced over a period of years greater yields of grain. In this connection the question arises whether the presence of awns upon florets of wheat causes an increase in weight of the enclosed kernels.

In 1889 and 1890, Hickman (4, 5)[3] reported an increase in yield of awned over awnless wheat. Over a period of 10 years using hundreds of varieties, the increased yield in favor of the awned varieties was 6 bushels per acre. About 26 years later, Fleischmann (1) isolated three types from native Hungarian wheat and propagated them further. Type A was awnless or slightly spurred, type B had awns as long as the glumes or shorter, and type C had awns longer than the glumes. Type A was generally inferior to the other two types, being lower in yield and producing lighter kernels. Type C was slightly better in most respects than type B and much better than type A. In 1919, Grantham (2) reported an increase of 3.31 bushels per acre in favor of awned wheat when 1,986 varieties were used in 26 trials. Treyakov (9), however, found that over a period of years at the Poltava station the awnless varieties outyielded the awned ones but individual grains from awned spikes were heavier than those from awnless spikes.

Several investigators have offered explanations for an apparent superiority of awned varieties. Perlitius (6) calls attention to the fact that awned cereal varieties under normal conditions ripen earlier than awnless ones. This, in many cases, might explain the differences in yielding ability. But he also says that the volume, weight, and ash content of the grain is increased by the transpiration of the awns. In some cases awned spikes transpired twice as much as either awnless ones or "de-awned" ones. Zoebl and Mikosch (11) in 1892 had already advanced this belief. They found that spikes of barley having awns transpired almost five times as much water as spikes from which the awns had been removed. These spikes were kept in distilled water having an oil film, the whole being weighed periodically. They also found that the greatest part of the water lost by the spike was through the awns and that the spikes transpired almost as much water as the upper three leaves of the culm. Vasilyev (10) reported results similar to those mentioned above. He varied his procedure in one case, however, when he cut off the awns from one-half of the spike and found that the kernels produced in these "de-awned" florets were 9% lighter in weight than those produced in awned florets.

In 1898, Schmid (7) wrote nine different articles on the structure and function of awns in the cereals. Using approximately the same method as that of Zoebl and Mikosch, he found transpiration from the spikes of many cereals, including

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[3]Figures in parenthesis refer to "Literature Cited," p. 287.

wheat, to be reduced one-sixth to one-third when the awns were removed from the cut-off spikes. The relative assimilation of awned vs. de-awned spikes was about 3:1, with much variation among the several cereals tested. The average weight of kernels from awned spikes was about 3.3% greater than that from de-awned spikes. When one-half of the spike was de-awned and compared with the other normal awned half, the difference in weight in favor of the awned kernels still remained 3.3%. In 1916, Tedin (8) compared plants of barley which had all the awns blown off the spikes shortly before ripening with normal plants in the same field. De-awned spikes ripened earlier and produced kernels whose average weight was 10% less than those on normal spikes. Eight varieties were used in this study. Harlan and Anthony (3) found kernels from spikes whose awns were clipped off to be lower in weight of dry matter and smaller in volume than those from normal spikes. This difference was not thought to be due to injury or the shock of removing the awns.

PRELIMINARY STUDIES INVOLVING INJURY TO FLORETS

In 1929, when experimenting with crossing technic in wheat, the author found kernels from spikes whose awns were clipped so low that part of the glumes was also removed to be smaller than those from normal spikes. Kernels from these "clipped" spikes weighed only 82.7% as much as those from similar awned spikes.

If kernels from "clipped" florets could be compared with those from homologous normal florets on the same spikes, errors due to variation in kernel size among different spikes could be avoided. Accordingly, all the spikelets on one side of several spikes were clipped at pollination time, while those on the opposite side of the same spikes were left untreated. The kernels from clipped spikelets weighed 85.1% as much as those from normal spikelets on the same spike. In another of these method studies the outer glumes only were removed from the spikelets of several awned spikes at about pollination time, while others were untreated. Kernels from spikes having the outer glumes removed weighed 92.1% as much as those from normal spikes. This suggests that even the outer glumes have an effect upon kernel size. This reduction in size is probably due to injury to and removal of nearby living tissue. That such is probably the case is indicated by the fact that Treyakov (9), Perlitius (6), Schmid (7), and Tedin (8) reported earlier ripening in the case of de-awned spikes.

EXPERIMENTS INVOLVING NO INJURY TO FLORETS

METHODS

If, then, kernels from normally awned and awnless florets found on the same spike could be compared, errors due to injury, as well as those due to selection of spikes, could be greatly reduced if not entirely eliminated. However, error due to position of the kernel on the spike would thus be introduced for "upper" kernels are normally somewhat smaller than "lower" kernels. In order to eliminate this error, a somewhat complicated procedure was necessary.

The F_2 progeny of a cross between Garnet (a variety with spur-like awns on a few of the upper lemmas) and Prelude (a fully awned variety) was divided into three classes of segregates as determined by the character of awns on the spikes.

These were (a) awnless (similar to the Garnet parent), (b) fully awned, and (c) intermediate, i.e., having long awns on the upper lemmas, shorter ones near the center of the spike, and none on the lower half of the spike.

Spikes with intermediate awms were selected at random. These were matched, individually, with awnless spikes of similar character and having the same number of spikelets. In all, 121 spike pairs, including 2,741 upper and 3,411 lower kernels, were thus obtained for detailed study. All kernels from awned florets on an intermediate spike were removed and weighed. After the removal of each kernel an homologous kernel on the paired awnless spike was removed and treated in a like manner. Comparisons of weight of kernels from awned with those from awnless florets on the same spike were now possible and error due to position of the kernel on the spike could be avoided by indirect comparison with homologous kernels on spikes without awns. Since all spikes were F_2 progeny of a cross, varietal differences were eliminated.

COMPARISON OF KERNELS FROM AWNED AND AWNLESS FLORETS OF THE SAME SPIKE

It was found necessary to report the results of these experiments as ratios. As an example, the weight ratio of kernels from awned (upper) florets compared with those from awnless (lower) florets on the same spike may be 0.99 for an intermediate or partially awned spike. For a paired awnless spike using homologous kernels the ratio may be 0.97. This gives a plus deviation of 2% between the two ratios. There were 121 intermediate spikes and 121 corresponding paired awnless spikes used in this experiment. Tables showing individual data from the 121 spike pairs would be too cumbersome to include in this paper. The ratio of upper (awned) to lower (awnless) kernels found on spikes with intermediate awns was 0.981. The corresponding ratio for homologous kernels on awnless spikes was 0.967. The average of the plus deviations was 4.3 and of the minus deviations was 2.9. The difference of 1.4% with odds of 27:1 in favor of kernels from awned spikelets is thought to be significant. Odds were obtained by applying Fisher's "t" distribution formula to the plus and minus deviations. These data show that kernels from awned florets tend to be somewhat heavier than those from awnless florets produced on the same spike.

Compared with the pronounced differences reported in the literature and the results of a preliminary test reported in this paper, which showed kernels from normal florets to be 15% heavier than those from clipped florets, this difference of 1.4% is not very great. It must be borne in mind, however, that in the preliminary test the awns had been clipped at about the pollinating stage and injury to the spikelets clipped at this early stage no doubt caused most of this reduction in average weight of kernels from clipped spikelets. In the experiment with which this paper primarily deals, however, the florets were not injured and error due to differences in position of the kernels upon the spike was practically eliminated.

COMPARISON OF AWNLESS,[4] INTERMEDIATE, AND AWNED SPIKES WITHIN AN F_2 PROGENY

If awned florets in general produce relatively larger and heavier kernels than awnless florets, it follows that awned spikes of the F_2

[4]Having a few spur-like awns.

population should produce heavier kernels than awnless ones, and intermediately awned spikes could be expected to produce kernels intermediate in these respects. Table 1 reports the results of an experiment planned to test this assumption. Awned, intermediate, and awnless spikes were selected at random from the F_2. The kernels were removed and weighed. The average weight of kernels from 280 awnless spikes was 18.5 mgm; from 300 intermediate spikes, 19.1 mgm; and from 199 awned spikes, 19.4 mgm. Their respective relative weights were 100.0, 103.2, and 104.9. These data show that kernels from awned spikes of an F_2 population are heavier than those from only partly awned spikes and that these in turn are heavier than those from awnless spikes. In this F_2 population, then, the presence of an awn upon the lemma of a floret tends to increase the weight of the kernel produced in that floret. It would be interesting to determine how composite seed of awned segregates would compare in yield with that of awnless segregates in later generations.

TABLE 1.—*Average weight of kernels from awnless, intermediate, and awned spikes selected at random from the F_2 of the cross Garnet x Prelude.*

Type	Number of spikes	Number of kernels	Average weight per kernel, mgm	Relative weights
Awnless	280	7,563	18.5	100.0
Intermediate	300	8,258	19.1	103.2
Awned	199	5,632	19.4	104.9

SUMMARY

By comparing kernels from awned and awnless florets borne on the same F_2 spikes, errors due to injury and to varietal, plant, and spike differences were practically eliminated. Due to the fact that kernel size is somewhat dependent upon the position of the kernel in the spike, it was necessary to compare homologous kernels of awnless spikes with those of intermediately awned but similar "paired" spikes. It is thought that results obtained from this experiment express fairly accurately the influence of the awn upon the average kernel weight.

Kernels from awned florets were found to be about 1.4% heavier, as an average, than those from awnless florets in the same spike. Furthermore, kernels from intermediately awned F_2 spikes were, as an average, 3.2% heavier than those from awnless F_2 spikes, while kernels from fully awned F_2 spikes were 4.9% heavier. The presence of awns on the florets of wheat tends toward the production of heavier kernels.

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MARGINAL SOIL AND FARM ABANDONMENT IN CAMPBELL COUNTY, WYOMING[1]

T. J. Dunnewald[2]

DURING the summer of 1935 the Agronomy Department of the University of Wyoming, in cooperation with the Bureau of Agricultural Economics, U. S. Dept. of Agriculture, started a soil survey of Campbell County, Wyoming, collecting at the same time information in each township as to cultivated areas, abandoned farms, vegetation, and kinds of crops. Such data were collected in 21 townships and a soil map completed during the past summer. This paper attempts to report progress and some of the findings and observations so far obtained.

SETTLEMENT

The area lies 60 miles west of the Black Hills with an annual average rainfall of 16 inches. This has been sufficient some years to encourage dry farming. Communities of farms have developed all over the county, separated by long stretches of unbroken sod pasture land used only for grazing.

The total cultivated area has reached a maximum of 15 to 16%. Dry years have tended to discourage farming and during the past summer nearly one-third of the area once cultivated has been abandoned or bears no crops but weeds. Eighty-five per cent of the total area of the 21 townships surveyed is covered with short grass vegetation. When spring rains are frequent, good grass is obtained in valleys, swales, and bottomlands. The wild hay is cut and stacked every summer and fall for winter use.

OWNERSHIP

County records show that the land has passed almost completely into private ownership. Of 1,035 parcels of land or farms, only 41 are now classed as public land. Of the 994 farms, less than half, or 462, are partly cultivated. The rest are owned by investors, homesteaders, speculators, real estate firms, and future bona fide farmers who have as yet made no attempt to break the sod, improve the land, or develop it into farms. Each of the 462 parcels which are farmed averaged 124 acres of cultivated land during the past year.

CROPS

In 5 of the 21 townships a map was constructed showing the location and kind of crop on all of the cultivated land found in these townships. Wheat was the crop which first attracted dry farming during the war.

[1]Contribution from the Agronomy Department, University of Wyoming, Laramie, Wyo. Received for publication January 18, 1936. Credit is due the following persons for aid in collection of field data: T. J. Glassey, U. S. Bureau Chemistry and Soils; and John Brock and Conrad Rohrer, Agronomy Department, University of Wyoming.

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Many farmers speak of 40 to 50-bushel yields of grain obtained during moist years. Corn also does well in moist years and is still the second most popular crop. The crops and their extent in percentage of the cultivated area during 1935 were as follows:

Crop	Acres	%
Wheat	3,390	29
Fallow	2,730	24
Corn	2,550	19
Rye	1,540	13
Oats	640	5
Barley	220	2
Alfalfa	200	2
Cane	130	1
Millet	110	1
Flax	30	1

SOILS

The soils in these townships were classified into 40 or 50 types, but for our purposes these may be grouped as (a) sandy loam soils, (b) medium to heavy soils, (c) red soils, and (d) rough stony or steep land.

The soils are chiefly residual in character, except along the streams, and are closely associated with the character of the parent rocks which are chiefly shales and sandstones and red clinker beds. The sandy loams occupy chiefly undulating to rolling country and low ridges projecting above the shales. These are the best dry farm soils for the average run of seasons. They are absorbent and porous and take up moisture rapidly from showers or melting snow. Where underlaid by heavier subsoils, the sandy loams serve as a moisture reservoir during dry spells and cultivation produces a dry surface mulch which prevents rapid loss by evaporation.

The medium to heavy soils are gray loams and clays which occupy the more level ground within the cultivated area. They tend to slick over during showers, producing a maximum run-off over the surface and a minimum absorption of moisture. In moist years these soils outyield the sandy loam soils, but in dry years the crops suffer more severely for lack of moisture. Corn, grain, and even grass tend to dry up and turn brown during the drought periods. Fall-seeded grain often does better than spring grain and matures before severe drought affects it.

The red soils are loams and sandy loams derived from the DeSmet clinker beds. These are layers of shale which have been burned red by the heat from burning coal beds. The clinkers are hard and flinty, resisting erosion, and occur on the tops of ridges and knolls capping the sandstones, chiefly in the west and northwest parts of the county. The clinkers produce a sandy surface soil with a heavy loam or clay loam subsoil which has good moisture-holding capacity.

All three of these soil groups are represented on the state experiment farm east of Gillette. Good crop yields have been obtained there and a fine grove of trees has been maintained all through the drought

years on the red sandy loam soils. Very little successful cropping has been obtained on the heavy, lower lying shale soils.

Rough stony and steep land, as the name implies, includes all stony, rough, and hilly lands. These are best adapted to grazing and cannot be cultivated successfully. Considerable blocks of such soils occur along the Powder River divide west of Gillette and bordering Pine Ridge along the east edge of the county.

MARGINAL LAND ON A SOIL TYPE BASIS

This is an area of mixed soil conditions in which are found soil types well adapted to dry farming under the climatic conditions imposed, together with some types occasionally adapted to crop production, and others distinctly best adapted to pasture or grazing at all times.

Judged by the amount of cultivation to date, not over 15 to 25% of the area surveyed is adapted to crop production, especially in periods of drought. The remainder of the area will always be best adapted for grazing except in years of abnormally large rainfall.

Dry farming has been attempted on enough types of soil so that the feasible ones are known. It would seem unwise to block off whole counties or even townships as marginal land and eliminate all crop production because the grazing area is a potential market for some of the products grown on the best soil in the neighborhood.

It is also expensive to maintain roads, schools, and local governmental activities where settlement is scattered and 25% or less of the soil can be successfully cropped over a period of years. However, none of these activities should be entirely dispensed with because a minor proportion of the soils are suitable for cultivation. Rather, it would be best to adapt the roads, schools, and governmental activity to a grazing type of agriculture. With large units in ranches and grazing land, the governmental units also should be large and inexpensive.

Migration out of the area in dry years is paralleled by a local shifting of farmers from the poorest land to farms with better improvements and prospects. This is a natural measure of adaptation and conservation which nature imposes and perhaps cannot be interfered with.

On the other hand, it appears that grass land unsuited to crop production when broken up requires 8 to 10 years to re-establish the grass cover and in the meantime the forage is also lost.

A solution for the present wasteful trial and error method of bringing these lands into agricultural use would appear to be a classification of the lands adapted to cropping and some regulation device tending to prevent the continued breaking up of the grass sod on soils which are clearly better adapted for grazing than for crop production.

THE EFFECT OF CERTAIN MANAGEMENT PRACTICES ON THE AMOUNT OF NITROGEN IN A SOIL[1]

P. E. KARRAKER[2]

FROM 1923 to 1934, an experiment was conducted on the Kentucky Agricultural Experiment Station farm at Lexington in which small plats were handled or cropped as follows:

Plats 1 and 4 kept bare by scraping.

Plats 2 and 5 in continuous bluegrass.

Plats 3 and 6 in continuous bluegrass and white clover.

The plats were 16 feet square, were in a line, separated by 3-foot bluegrass strips, and were numbered consecutively.

In September, 1923, and again in the following February, plats 2 and 5 were seeded to bluegrass and plats 3 and 6 to bluegrass and white clover. White clover also was reseeded in plats 3 and 6 several times during the experiment.

Thru 1928, the vegetation on these plats was not disturbed except that it was removed when thought necessary to maintain the stand. The dates when this was done and the amounts of dry material and nitrogen removed are shown in Table 1. After 1928 the vegetation was clipped from time to time with a lawn mower and left on the plats.

Care was taken to remove any legume plants appearing in plats 2 and 5 but, in the main, the other volunteer plants which survived the clipping treatments were allowed to grow. The stand of bluegrass on these plats varied from good at the beginning of the experiment to fair at the close, but the bluegrass became rapidly less vigorous from the beginning of the experiment and, after 1928, the larger part of the growth was mainly volunteer annual grasses, particularly crabgrass. However, because of insufficiency of available nitrogen, none of the plants in these plats made vigorous growth after the first few years of the experiment.

Considerable sweet clover grew on plats 3 and 6 in 1925 until the middle of July when it was killed by cutting. It was left on the plats. Before cutting, it was 3 to 4 feet high and covered the ground fairly well. Other than the sweet clover just mentioned, the vegetation on these plats during the experiment was mainly bluegrass and white clover. Because of the several reseedings, white clover perhaps formed a larger part of the total vegetation than in the average bluegrass pasture but, in the main, the amount and composition of the plant growth on these plats was very similar to that in an average bluegrass pasture in this section. The comparatively vigorous growth of vegetation on these plats contrasted sharply with the weak growth on plats 2 and 5, particularly after the first few years of the experiment. The quantities of vegetable material removed from the plats on May 28, 1926, and May 25 and July 26, 1928 (Table 1) are comparable

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[1]The investigation reported in this paper is in connection with a project of the Kentucky Agricultural Experiment Station, and is published by permission of the Director. Received for publication February 1, 1936.

[2]Associate Professor of Soils.

TABLE 1.—*Air-dry material and nitrogen removed from the plats.*

Date of removal	Nature when removed	Pounds per acre removed	
		Dry matter	Nitrogen
	Plat 2		
May 28, 1926	Green	879	10.2
Mar. 25, 1928	Dead material from previous year	2,552	27.8
May 25, 1928	Green	217	4.6
July 26, 1928	Green	1,687	21.5
Total			64.1
	Plat 5		
May 28, 1926	Green	868	11.0
Mar. 25, 1928	Dead material from previous year	3,337	40.0
May 25, 1928	Green	154	3.3
July 26, 1928	Green	1,431	20.6
Total			74.9
	Plat 3		
May 1, 1926	Dead material from previous year	2,817	42.5
May 28, 1926	Green	2,810	42.9
Dec. 7, 1926	Most of top growth	2,684	35.9
Mar. 25, 1928	Dead material from previous year	3,124	65.8
May 25, 1928	Green	266	8.1
July 26, 1928	Green	3,827	74.4
Total			269.6
	Plat 6		
May 1, 1926	Dead material from previous year	3,669	72.9
May 28, 1926	Green	1,995	33.9
Dec. 7, 1926	Most of top growth	3,721	53.0
Mar. 25, 1928	Dead material from previous year	4,674	65.4
May 25, 1928	Green	289	8.8
July 26, 1928	Green	3,084	51.6
Total			285.6

and indicate the differences in growth in these years. The total material removed from each of the plats at these dates in pounds per acre was as follows: Plat 2, 2,783 lbs.; plat 5, 2,453 lbs.; plat 3, 6,903 lbs., and plat 6, 5,368 lbs.

The soil on which these plats are located is a Maury silt loam. The pH is about 5.5. The phosphorus and potassium, determined in a composite sample of surface soil from an adjoining area, are 4,680 and 24,000 pounds, respectively, per 2,000,000 pounds of dry soil.

The plats were sampled for nitrogen analysis in September, 1923, October, 1924, and November, 1931. The 0 to 6 and the 6 to 18 inch layers were sampled. These were assumed to weigh 2,000,000 and 4,000,000 pounds per acre, respectively. At each time nine cores were taken from a plat. In 1924 and 1931, these were located 4 to 6 inches away and in opposite directions from those in 1923. The sampling in 1924 was done to check the nitrogen analysis of the previous sampling.

The 1923 and 1924 analyses are shown in Table 2. The average of these analyses, the analyses of the 1931 samples, and the changes in nitrogen from the 1923–24 to the 1931 samplings are shown in Table 3.

TABLE 2.—*Nitrogen in the soil of the plats in 1923 and 1924 stated as pounds per acre.*

Plat No.	0–6 inches		6–18 inches	
	1923	1924	1923	1924
1	2,883	2,796	3,964	4,112
4	2,905	2,799	3,482	3,402
2	2,735	2,760	3,408	3,400
5	2,843	2,838	3,572	3,512
3	2,914	2,914	3,618	3,620
6	3,007	3,073	3,928	4,228

TABLE 3.—*Nitrogen in the soil of the plats in 1923–24 and in 1931, and the change in nitrogen stated as pounds per acre; also, the average total nitrogen in the vegetable material removed from the plats.*

Plat No.	0–6 inches			6–18 inches			0–18 inches		Av. total nitrogen in vegetable material removed
	Av., 1923–24	1931	Loss (—) or gain	Av., 1923–24	1931	Loss (—) or gain	Loss (—) or gain	Av. loss (—) or gain	
				Bare Scraped					
1	2,840	2,454	—386	4,038	3,880	—158	—544	—530	—
4	2,852	2,517	—335	3,442	3,262	—180	—515		
				Bluegrass					
2	2,748	2,580	—168	3,404	3,514	110	— 58	62	70.0
5	2,841	2,783	— 58	3,542	3,782	240	182		
				Bluegrass and White Clover					
3	2,914	3,006	92	3,620	3,732	112	204	405	278.
6	3,040	3,291	251	4,078	4,432	354	605		

The decrease in nitrogen in the plats kept bare and the increase in nitrogen in the plats in bluegrass and white clover will be noted. The average decrease in the former was at the rate of about 76 pounds per acre per year (counting from 1924) and the average increase in the latter at the rate of about 58 pounds per acre per year. An average of 277.6 pounds of nitrogen per acre also was removed from the latter two plats in vegetable material during the first part of the experiment. The greater increase in nitrogen in the soil of plat 6 than in the soil of the duplicate plat 3, in part at least, is because of the larger plant growth, particularly of legumes, in the former plat than in the latter.

Notwithstanding the absence of legume plants and the small growth of vegetation on plats 2 and 5, as an average, nitrogen remained about constant in the soil of these plats during the period. As an average of the two plats, 69.5 pounds of nitrogen per acre, also, were removed

from the plats in vegetable material. There is an appreciable difference between these duplicate plats in the change in amount of nitrogen in the soil between sampling dates for which there is no specific explanation. In both plats, also, the surface soil decreased in nitrogen, but the sub-surface soil increased in nitrogen.

The fact that nitrogen did not decrease in these plats probably is at least largely because the continuous grass cover, even tho not vigorous, prevented practically all nitrogen losses. The plats were almost level so that practically no erosion took place. The nitrogen added in precipitation also should be considered in this connection. In work done in another experiment, this was found to be about 10 pounds per acre from April 1, 1934, to April 1, 1935. Perhaps this is about the average amount of nitrogen brought down in the precipitation from year to year on the Experiment Station farm. It appears not to be necessary, in accounting for the maintenance of nitrogen in the soil of these plats, to assume that any appreciable amount of nitrogen was fixed non-symbiotically. On the other hand, obviously the findings do not preclude some addition in this way. However, the soil was too acid to be favorable for nitrogen fixation by azotobacter.

The plats were plowed the last of April, 1934, and seeded to Sudan grass the last of May. The crop was cut twice. The dry matter and nitrogen in each cutting was ascertained. This was done to find out the effect of the previous treatments on the amount of nitrogen available to a crop in the soil of the various plats. The data are shown in Table 4. The effect of the treatments on yield and nitrogen content of the Sudan grass can be seen in the table.

TABLE 4.—*Dry matter and nitrogen in the Sudan grass in pounds per acre.*

Plat No.	Cutting, July 31		Cutting, Oct. 2		Total, two cuttings	
	Dry matter	Nitrogen	Dry matter	Nitrogen	Dry matter	Nitrogen
1	2,720	27.7	1,337	10.2	4,057	37.9
4	2,244	24.5	1,100*	9.0*	3,344	33.5
2	3,434	33.3	1,854	14.3	5,288	47.6
5	3,706	39.3	2,281	16.2	5,987	55.5
3	4,080	51.0	2,866	20.0	6,946	71.0
6	4,386	70.6	3,417	27.3	7,803	97.9

*This plat apparently received an addition of nitrogenous material after the July 31 cutting, since the vigor and color of the growth indicated considerable available nitrogen. The dry matter and nitrogen in the table were calculated from the July 31 figures for this plat by using the ratio between the July 31 and October 2 figures obtaining for plat 1.

SUMMARY

From 1923 to 1933, small plats were handled in duplicate as follows on the Experiment Station farm at Lexington: (1) kept bare by scraping, (2) in continuous bluegrass, and (3) in continuous bluegrass and white clover. Sweet clover grew in the bluegrass-white clover plats in the first half of 1925 and an appreciable part of the vegetation in the bluegrass plats during the latter years of the experiment was volunteer nonlegume plants. Vegetation was vigorous on the bluegrass-white

clover plats during the experiment, but poor on the bluegrass plats after the first few years of the experiment. Vegetation was removed from the plats at certain times through 1928. Thereafter, the plats were clipped several times a year and the clippings left on the plats.

Nitrogen was determined in the 0 to 6 and 6 to 18 inch soil layers of the plats at the beginning of the experiment and again in 1931. The average change in nitrogen during this period in the soil of the plats to a depth of 18 inches was in pounds per acre for the bare plats, 530 lbs. loss; for the bluegrass plats, 62 lbs. gain; and for the bluegrass-white clover plats, 405 lbs. gain. The average amount of nitrogen contained in the vegetable material removed from the plats was in pounds per acre for the bluegrass plats, 70 lbs.; and for the bluegrass-white clover plats, 278 lbs.

The plats were plowed and Sudan grass grown in 1934 to determine the effect of the treatments on the amount of nitrogen available to a crop.

CAPILLARY CONDUCTIVITY DATA FOR THREE SOILS[1]

L. A. RICHARDS[2]

WHEN a soil transmits or conducts water, the flow takes place through a complicated but connected region of liquid water. It is convenient to express this flow as the product of a conductivity factor and the total water moving force, this latter being the vector sum of the forces arising from the pressure gradient in the water system and gravity.[3] Thus,

$$\text{Flow} = \text{Conductivity x Water Moving Force.} \qquad 1$$

This well-founded empirical equation is sometimes referred to as the generalized form of Darcey's law and may be employed when the soil pore spaces are wholly or only partially filled with water.

For this latter case, i.e., when the soil is not saturated, it is evident the thickness of the water-conducting films, and hence the conductivity factor, will depend on the moisture content of the soil. Likewise, the pressure in the liquid water depends on the moisture content of the soil. Referred to atmospheric pressure as the zero reference, the pressure in water in an unsaturated soil is negative and it will occasionally be desirable to use the term tension as a name for this negative pressure. Further, using the terms capillary tension and capillary conductivity will make it clear that water relations in unsaturated soil are being considered.

One has considerable freedom in defining and choosing units for the quantities occurring in equation 1. In the present article, the water moving force will be expressed in dynes per gram and the flow as the number of cubic centimeters of water which in 1 second cross a square centimeter area in the soil, this area being taken perpendicular to the direction of flow. The capillary conductivity as here expressed in c g s units is simply the volume of water which in 1 second crosses unit area perpendicular to the flow per unit water moving force.

The capillary conductivity is a function of the various soil parameters, but may be thought of as a variable factor in which we may group

[1]Journal Paper No. J-326 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 487. The curves shown in this article were included in a paper presented by the author at the annual meeting of the Society in Chicago, December 6, 1935. Received for publication February 5, 1936.

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[3]The gravity w. m. f. (water moving force) per unit mass is equal to g, the acceleration of gravity. The pressure w. m. f. per unit volume of liquid is equal to the pressure gradient in the liquid. Hence, the pressure w. m. f. per unit mass is equal to the pressure gradient divided by the density. In mathematical treatments of the dynamics of soil moisture these forces have been expressed as the gradients of the gravitational and capillary potentials (1, 3). We have the equation,

$$-\text{grad}\,\Psi^{c} = -(\text{grad } p)/d = (\text{grad } t)/d, \text{ where } \Psi^{c}, p, t, \text{ and } d$$

are respectively the capillary potential, capillary pressure, capillary tension, and density of the soil water. Under conditions where we may assume d is equal to unity, we may write $-\Psi^{c} = -p = t$, numerically. In moist soil Ψ^{c} and p are negative while t is positive. Dimensionally, Ψ^{c} is given as work per unit mass while p and t have the units of pressure which are force per unit area.

the many things we do not know about the way these parameters affect the moisture-transmitting properties of the soil.

Ohm's law, which is directly analogous to equation 1, has served as one of the primary foundations of applied electricity for about a century and yet physicists have only recently been able to calculate from fundamental data values for electrical conductivity which are in approximate agreement with experimental values. Similarly, for soils, it is not too optimistic to expect that at some time in the future, when certain given data on the composition and state of packing, we shall be able to calculate the capillary conductivity. In the meantime, however, we may use equation 1 and experimental values of the capillary conductivity for expressing soil moisture flow quantitatively.

SIGNIFICANCE OF CONDUCTIVITY DATA

There are as yet but scanty data available on the capillary conductivity. The author has previously (3)[4] given curves which indicate the way in which the conductivity of three soils depends on the capillary potential. Earlier published data (2) relating the moisture content to the capillary potential of these soils makes it possible to determine the relation between the moisture content and the capillary conductivity. The data in Table 1 were taken from the papers just cited and the curves in Fig. 1 show the way in which the conductivity changes with moisture content in these soils.

TABLE 1.—*Relation between moisture content and capillary conductivity.*

Capillary tension equivalent water column in cm	Moisture content per cent, dry basis	Capillary conductivity, seconds x 10^{11}
	Sandy Soil	
0	23	——
20.3	13	930
138	6.3	16.4
243	5.4	6.95
	Greenville Loam	
0	40.1	——
32.1	34	342
85.2	28.6	340
161	22.4	310
248	19.9	257
393	17.2	178
597	15.4	72.7
	Preston Clay	
0	68.5	——
14.3	63.3	460
149	42.2	3.28
27.1	59.0	135

The range of moisture contents for which experimental values were obtained should be extended in each case, but the significance of such data in predicting important moisture characteristics of soils is easily seen. Except for the intermediate point on the Preston clay curve, the

[4]Figures in parenthesis refer to "Literature Cited," p. 300.

data were taken as the moisture content was continuously decreased, but it is expected that a small hysteresis effect would not appreciably alter these curves.

The numbers at the ends of the curves indicate the corresponding tension in the soil water expressed as the number of cms of water column necessary to produce these tensions. The places where the

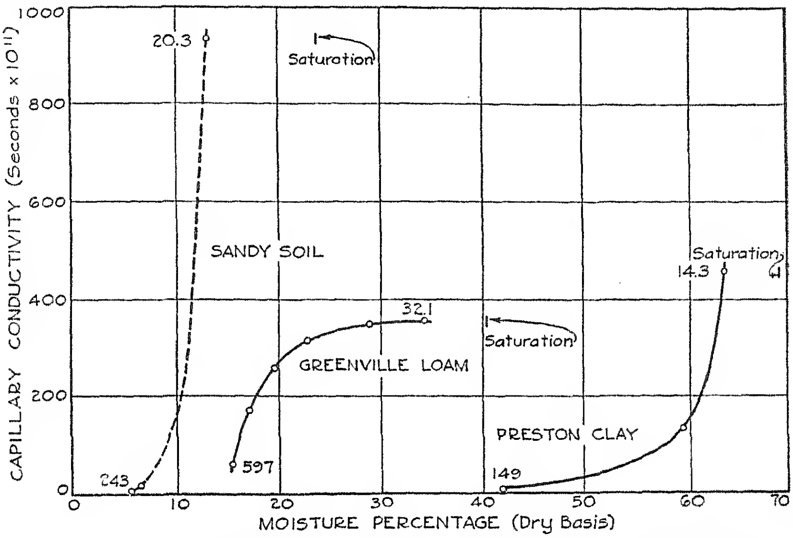

FIG. 1.—Curves showing the relation between capillary conductivity and moisture percentages for three soils: A, sandy soil; B, Greenville loam soil from the College farm, Logan, Utah; C, clay from Preston, Idaho. The numbers at extreme points on the curves indicate the corresponding capillary tension. Curve A is represented with a dashed line because the capillary tension-moisture percentage curve for a similar but not identical soil was used to transform the independent variable of the conductivity function from capillary tention to moisture percentage.

curves meet the moisture axis indicate the percentage at which the water in the soil is no longer present in a continuous liquid phase and capillary flow ceases. At the other extreme, when saturation is reached, the conductivity has its maximum value and no longer depends on the tension or pressure in the soil water. The temperature and state of packing of the soils were held constant during the conductivity determinations, but with due consideration of these factors such data may be applied to field conditions.[5]

An analysis of the curves yields such information as the following: Downward flow will keep the sandy soil A well drained because for moisture percentages above 13 the conductivity is high and allows the water to drain off quickly under the action of gravity. The conductiv-

[5]The first power of the reciprocal of the coefficient of viscosity of the capillary liquid is implicitly involved in the capillary conductivity as here used. Hence, the quantity will have a large temperature coefficient. For certain purposes it will be desirable to eliminate this viscosity factor and obtain a conductivity function, depending only on the liquid content and the composition and structure of the soil.

ity of the Greenville loam soil B remains fairly high even at the tension corresponding to a 590 cm water column, thus enabling this soil under certain conditions to raise appreciable quantities of water this distance from a water table. The low tension at the zero conductivity cut-off for the Preston clay C indicates that the maximum height to which water could rise by capillary action in this clay is 150 cm. On the other hand, the high moisture percentage at cut-off indicates that downward flow under the action of gravity would not reduce the moisture percentage below 40; hence, this clay soil will act as a good reservoir for precipitation.

With the soils for which data are given in this paper, the conductivity cut-off points were not actually reached, but it is seen that for the sand and clay soils used the conductivity values become small at moderately low tensions. It is evident that porous clay apparatus for measuring or controlling the capillary tension of soil can be successfully used only at moisture contents where the conductivity is appreciable.

SUMMARY

Curves are given which show the relation between the capillary conductivity and the moisture percentage for a sand, a loam, and a clay soil.

The relation of these curves to important moisture characteristics of soils, such as water storage, drainage, and maximum heights of capillary rise from a water table, is pointed out.

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STUDIES ON THE USE OF THE TERRACING PLOW FOR SOIL CONSERVATION[1]

HORACE J. HARPER[2]

THE terracing plow is an important agricultural implement because it can be used to build terrace ridges or it can be converted into a general purpose plow by replacing the terracing wing with a standard moldboard. One of the reasons why the terracing plow has not been used more extensively in the control of soil erosion is due to the fact that the terrace ridge cannot be completed in one operation. The loose soil must be packed by rainfall before it can be plowed a second time in order to increase the effective height of the ridge. Ramser,[3] in discussing the need of improving machinery for terrace construction, states that more than one plowing is needed to build a terrace ridge having a proper height. Smith[4] states that the terrace plow is effective for three rounds after which it acts like an ordinary plow, and that the small farmer who wishes to terrace a few acres can afford to consider this type of terracing equipment.

The cost of terracing tools has been one factor which has retarded the program of soil conservation in many areas. Although the cost of terracing equipment varies considerably, there are many farmers who are not able to purchase tools which are frequently recommended and used in terracing demonstrations. Since power is available on the average farm to operate a plow and since the average farmer can supply labor when he cannot supply capital, the terracing plow could be an important factor in the expansion of a soil conservation program which is seriously needed in many areas to reduce soil losses which occur as a result of the uncontrolled movement of run-off water.

EXPERIMENTAL

For several years studies have been in progress at the Oklahoma Agricultural Experiment Station in order to determine what methods should be used to reduce the rate of soil erosion on land which has been abandoned because it will not produce satisfactory yields of cultivated crops. The major portion of this land is low in fertility and unpalatable species of grass and weeds occur on these areas as a subclimax vegetation. Because of a lack of vegetative cover on these soils, erosion continues at a relatively rapid rate and small gullies develop into canyons with overfalls which are difficult to control. It was observed that the banks of shallow ditches are soon covered with

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[2]Professor of Soils. The author is indebted to the G. A. Kelly Plow Company, Longview, Texas, for assistance in connection with this study, and to L. E. Hazen, who supplied the dynamometer which was used to obtain data on the draft of different plows.

[3]RAMSER, C. E. The need of improved machinery for terrace construction and farming terraced lands. Agr. Eng., 12:39–42. 1931.

[4]SMITH, H. P. Types of terracing machinery used in Texas. Agr. Eng., 12:43–44. 1931.

grass, but that enormous amounts of soil must be removed by erosion before the banks of deep gullies recede far enough from the center of the gullies so that grasses can establish a cover which will reduce the erosive effect of torrential rain.

An attempt was made to increase the growth of vegetation in several ditches in order that the soil which is removed from the banks by natural processes would be held by the grass and would gradually fill the ditch. A ditch-filling plow which is designed to move loose earth was used in some of these experiments, but the results were not satisfactory. The lower edge of the moldboard scraped the surface of the ground very much like a grader blade and interfered with the action of the plow in firm soil. The weight of the plow was also objectionable when it was necessary to lift the plow from one position to another in order to transfer a maximum amount of soil from the upper edge of the banks of crooked gullies into the bottom of the ditch. When this plow was used to construct a terrace ridge the soil was not discharged quickly from the end of the moldboard and a side draft developed which made the plow very difficult to handle.

Experiments conducted with a small terracing plow demonstrated that this tool was easier to handle than the ditch-filling plow and was more effective than an ordinary moldboard plow in moving soil laterally; consequently more soil could be transferred into a gully by operating the terracing plow along the edge of the bank. Although a terracing plow is a good tool to use in transferring surface soil into a gully, experiments have shown that the banks of a gully should not be disturbed until some provision is made to prevent run-off water from removing the loose soil which falls to the bottom of the ditch. Inexpensive barriers can be constructed to hold the soil until a good growth of vegetation can be established and in addition some method should be used to reduce the quantity of run-off water which enters the ditch under ordinary conditions.

Contour ridges are very effective in reducing the quantity of run-off water occurring on overgrazed pastures or eroded fields which are not in cultivation and these ridges are easily constructed with a terracing plow. Small ridges having an effective height of at least 6 inches above the level of the ground after the soil is packed were built in six rounds with this implement. Run-off water cannot be controlled on steep slopes unless numerous ridges are constructed. When a walking plow similar to that shown in Fig. 1, No. 1, was used to build contour ridges, the third and fifth rounds were plowed in the subsurface soil. This soil contains fewer grass roots than the surface layer and it can be used to fill the openings between the sods to increase the effective height of the ridge in order that more run-off water may be held in the depression on the upper side of the contour furrows.

In some of the experiments soils were encountered which contained considerable amounts of clay, and when moisture conditions were not favorable for tillage, these soils would stick to the outer end of the straight terracing moldboard, as shown in Fig. 1, No. 1, and obstruct the movement of the soil from the furrow to the terrace ridge. It was also observed that this moldboard did not operate satisfactorily when sods were numerous and the plow could not be handled easily

on the inside of sharp curves in the furrow. In order to overcome this objection, the outer end of the straight moldboard as shown in Fig. 1, No. 1, was cut off and a flat piece of steel was attached at an angle

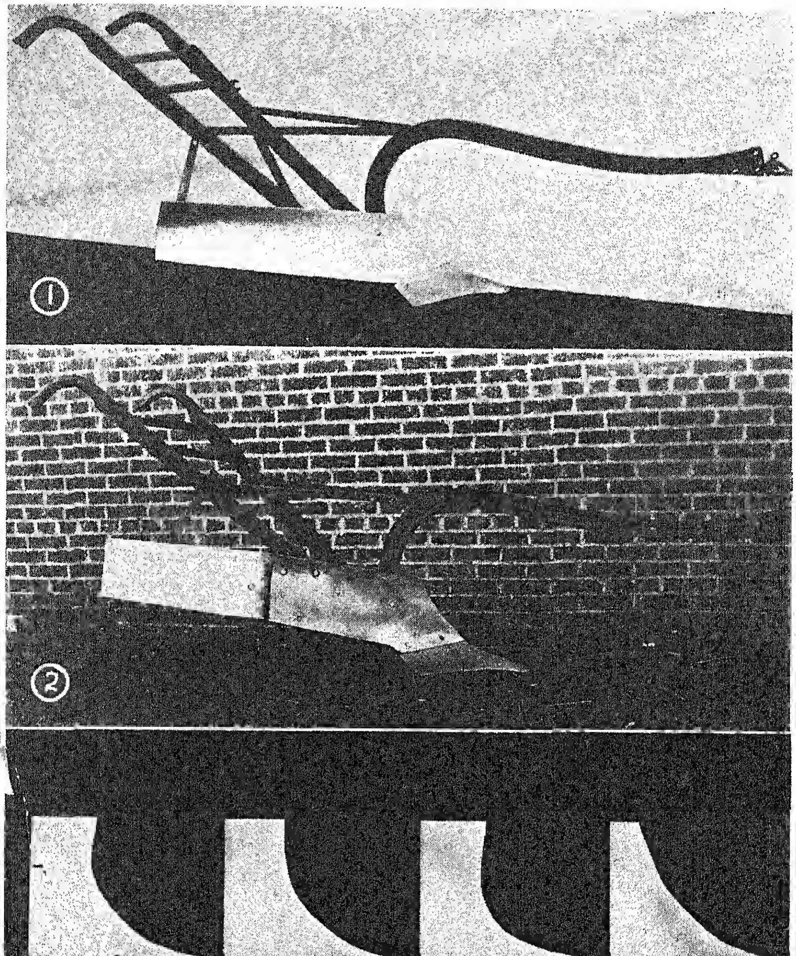

FIG. 1.—1, Terracing plow. 2, Terracing plow with modified moldboard. 3, Curvature of different moldboards, cross section shown from edge of share to top of moldboard 10 inches from landside. (1) Special terracing moldboard. (2) Regular terracing moldboard. (3) Moldboard on a mixed land plow. (4) Moldboard designed for black clay soils.

which would reduce the tendency for the soil to stick to the polished surface. The width of the moldboard was also increased by raising it 2 inches and welding a strip of steel to the lower edge of the moldboard where it fits against the share. The modified moldboard is illustrated in Fig. 1, No. 2. This change in the shape of the moldboard improved the operation of the plow in sticky soil, on sharp curves along contour ridges, and in plowing pasture contours where the sod did not pulverize easily.

A study of the design of terracing moldboards as compared with ordinary turning plows indicates that the terracing moldboard should have a higher lift than that which occurs on a general purpose plow. Fig. 1, No. 3, shows a cross section of four different plows which were studied in these experiments. The diagrams at the left which are marked 1 and 2 were taken from terracing plows which were used in these experiments and show the cross section from the edge of the share to the top of the moldboard at the point where the share and moldboard meet opposite the landside. Diagram 3 was taken from a general purpose moldboard and 4 from a plow designed to handle soils containing high percentages of clay. A "black land" plow is not satisfactory from the standpoint of building terrace ridges because it is not designed to lift the soil, although it scours better than an ordinary plow in compact clay soils. The problem of scouring is also associated with the steel which is used in the construction of the moldboard. The use of soft center steel in the construction of the terracing moldboard would improve the operation of the plow in sticky soil.

Fig. 2, No. 1, shows a terracing moldboard which has been attached to a riding plow. The long wing is very effective in moving loose soil toward the terrace ridge. This arrangement has some advantages over the walking plow equipped with a terracing moldboard, especially in clay soils where it is sometimes difficult to hold the walking plow in the ground when the outer end of the moldboard comes in contact with large masses of soil which do not pulverize readily. Fig. 2, No. 2, shows a riding plow equipped with a straight terracing moldboard. This plow can be used to build terrace ridges in soils which contain enough sand to cultivate easily. Fig. 3, No. 1, shows an overgrazed pasture which has been protected from surface erosion by the construction of contour ridges. A close spacing of the ridges is desirable in order to retain as much of the rainfall as possible and reduce the damage which occurs from run-off water. The terrace ridge in Fig. 3, No. 2, has been plowed once. Soil should be moved toward the ridge each time the land is plowed in order to increase the width and height of the barrier which is needed to protect cultivated land from run-off water.

When terrace ridges are built with a plow the area of subsurface soil which is uncovered is negligible as compared with conditions which exist after a grader or a V drag has been used. Frequently the major portion of the top soil is removed from strips of land several feet wide on each side of the terrace ridge when a grader is used to build the ridges. Because of the high clay content and lower amount of organic matter in the subsurface soil, poor crops are produced on the denuded areas for several years. When terrace ridges are con-

structed with a terracing plow, only the dead furrow between the ridges will suffer if the soil is moved toward the ridge each time the land is plowed.

Studies on the draft of the terracing plow indicate that the power required is similar to that of an ordinary plow when the soil is being moved laterally. The results of these experiments are given in Table 1.

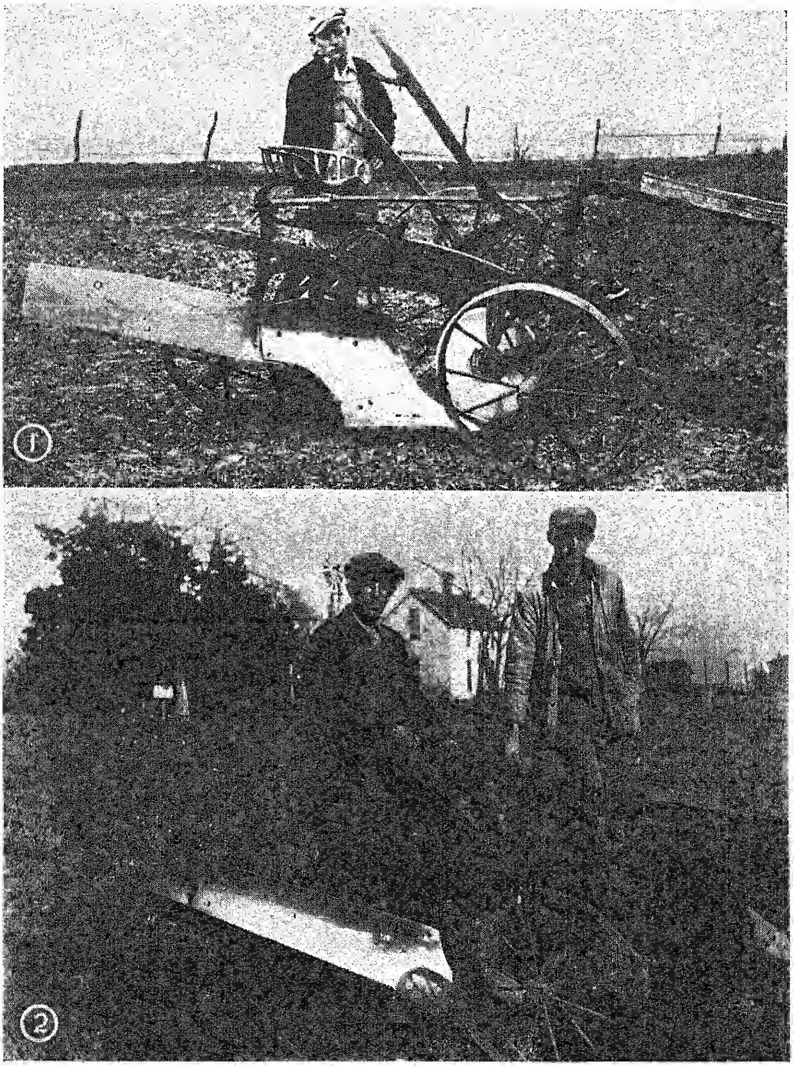

FIG. 2.—Experimental studies on terracing plows. 1, Modified terracing moldboard attached to a riding plow. 2, Regular terracing moldboard attached to a riding plow.

TABLE 1.—*Studies on the draft of a general purpose plow as compared with a terracing moldboard attached to the same share; data on the draft of a small terracing plow also included.*

Test No.	Soil type	Surface or subsurface soil	Drawbar pull in pounds per square inch of cross section of the furrow slice		
			14-inch share, ordinary moldboard	14-inch share, terracing moldboard	10-inch share, terracing moldboard
1	Derby sand	Surface	4.58	5.76	7.00
2	Derby sand	Subsurface	——	10.71	16.80
3	Vernon clay loam	Surface	8.57	7.85	10.00
4	Vernon clay loam	Subsurface	15.71	11.78	19.80
5	Kirkland fine sandy loam	Surface	5.00	6.28	5.13
6	Kirkland fine sandy loam	Subsurface	14.84	14.84	19.55
7	Kirkland fine sandy loam	Surface*	9.43	10.71	11.00
8	Kirkland fine sandy loam	Subsurface	17.46	14.50	19.55

*Native pasture; all other areas were in cultivation.

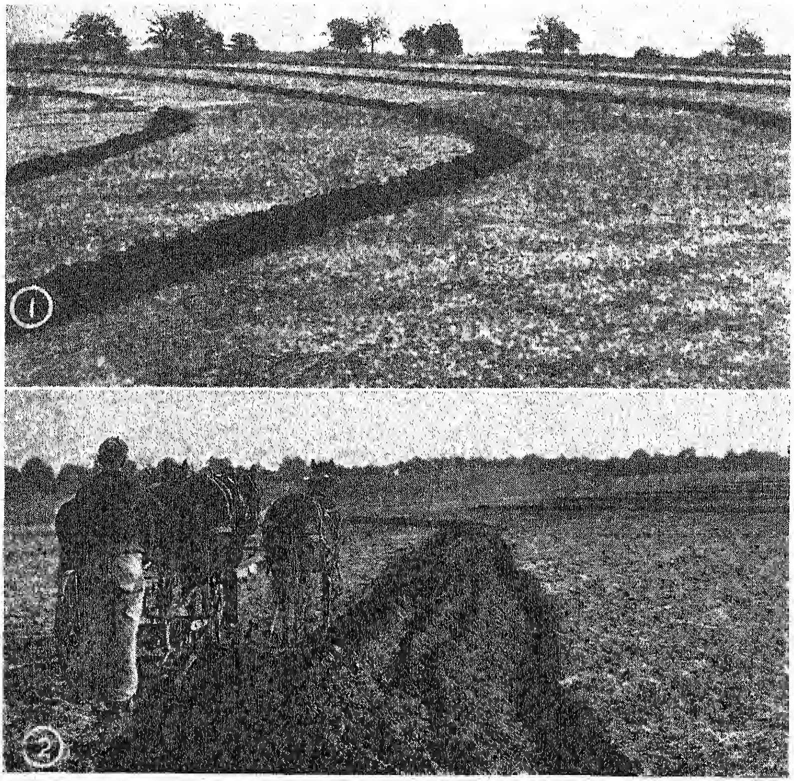

FIG. 3.—Studies on soil conservation. 1, Contour furrows protecting overgrazed pasture from erosion. 2, Building the terrace ridge with a terracing plow.

Some variation occurred in the depth of the surface and subsurface furrows in the different soil types and this may account for some of the differences in drawbar pull which were obtained in this experiment. The depth of the surface furrows varied from 5 to 6 inches, and the subsurface furrows varied from 4½ to 5½ inches. A walking plow was used in this experiment and was operated twice in the same furrow by shifting the hitch on the end of the beam. All measurements were made with an oil pressure dynamometer.

A considerable increase in draft occurs when the terracing plow is operated at a depth of 10 inches and the soil is raised toward the top of the terrace ridge. Data on the 10-inch terracing plow were included in this experiment, although no information was obtained to show the relative difference between the draft of this plow as compared with an ordinary moldboard attached to the 10 inch share. For some reason the draft per square inch of cross section of the furrow slice was greater when the 10-inch plow was used as compared with results obtained with the 14-inch terracing plow. A considerable amount of soil fell over the upper edge of the terracing moldboard when the 10-inch plow was used, which would indicate that the quantity of soil which was being moved was greater than the plow was designed to handle. It is interesting to note that the draft of the terracing moldboard attached to the share of the walking plow was frequently lower than the draft of the same plow equipped with a general purpose moldboard. The force required to move loose soil laterally is evidently small as compared with the power needed to cut and lift the furrow slice. About twice as much energy was required to pull the plow when it was operating in the subsurface soil. The higher clay content of the subsurface layers and the greater lift which was required to push the soil onto the terrace ridge was responsible for this condition.

Further studies on the draft of four different types of terracing plows were made on a deep sandy soil and these results are given in Table 2. Plow No. 1 and plow No. 2 were obtained from companies who sell terracing plows, while plows Nos. 3 and 4 were equipped with special moldboards which were designed to improve the operation of the plows under certain soil conditions.

TABLE 2.—*A comparison of the draft of different terracing plows operating in a fine sandy loam soil.*

Plow No.	Width of share in inches	Drawbar pull in pounds per square inch of cross section of furrow	
		Surface soil, 0 to 6½ in.	Subsurface soil, 6½ to 13 in.
1	10	8.15	14.92
2	10	8.15	—
3	12	7.69	11.54
4	10*	7.50	12.87

*Special moldboard as shown in Fig. 1, No. 2.

There is some evidence to show that plows Nos. 1 and 2 had a slightly higher draft than plows Nos. 3 and 4. Plow No. 2 was equipped with a moldboard similar to that shown in Fig. 1, No. 2, except

TABLE 3.—*A comparison of the draft of different terracing plows operating in a soil having a compact clay subsoil.*

Plow No.	Width of share in inches	Drawbar pull in pounds per square inch of cross section of furrow	
		Surface soil, 0 to 6 in.	Subsurface soil 6 to 10 in.
1	10	11.90	32.67
2	12	10.26	35.40†
3	10*	9.63	31.43

*Special moldboard as shown in Fig. 1, No. 2.
†Furrow depth, 0 to 7 inches in surface and 7 to 12 inches in subsurface soil.

that the moldboard was made in one piece. Three of these plows were compared on a shallow soil which had a very dense, compact clay subsoil and the results of this test are given in Table 3.

The most important information which was obtained in this experiment was the enormous increase in power required to move the subsurface soil as compared with the power required to turn the surface layer. It was quite evident that the large plow was more effective in handling the compact subsurface soil than the smaller plows. This information may be of some value in the development of a plow which can be used to terrace soils which are high in clay content.

The draft of a small terracing machine equipped with a 7-foot blade and set at a sharp angle to cut a furrow slice varied from 1,660 to 1,725 pounds when the point of the blade was cutting about 3 inches deep. A special 14-inch terracing plow operating in the same soil at a depth of 6 inches had a drawbar pull of 710 pounds. When this plow was moving a furrow slice from the subsurface soil at a depth of 6 to 12 inches, which was the second round in the same furrow, the drawbar pull was 1,375 pounds.

When a riding plow is used, it is necessary to plow a deep narrow furrow in order to build a terrace ridge of maximum height in one operation. Although the ridge which is built by one plowing is relatively narrow, it can be plowed a second time as soon as rainfall packs the soil. If small grain is planted on the area a second plowing can occur as soon as the roots of the plants are large enough to hold the soil together. Even though some of the ridges are broken by run-off water during periods of excessive rainfall, very little erosion will occur between the terrace ridges when the surface of the ground is covered with vegetation.

Low terrace ridges are more effective in controlling erosion on small fields than on large fields; however, the terracing plow is not limited to small fields with gentle slopes. There is no reason to believe that tractor plows can not be equipped with terracing moldboards and the job of terracing accomplished at the same time the land is plowed in order to reduce the cost of construction.

The terracing plow may also be used to mark the contours on land where soil erosion is controlled by strip cropping. On fields where the slope is not too great many small terrace ridges should be more effective in the conservation of rainfall than a few large ridges which

actually increase the slope of the land because of the deep ditches which are dug in order to build the terrace ridge.

Soil conservation is a problem which must be solved in most cases by the individual who owns or operates the land. A program of education must precede field operations. Enough evidence has been obtained in this investigation to show that the terracing plow can be used to control run-off water effectively from cultivated fields and overgrazed pastures when the slope of the land does not exceed 6 or 8%.

SUMMARY

Studies on the terracing plow were made to determine its limitations in a soil conservation program. It is an inexpensive tool and can easily be operated by the power available on the average farm.

It was found that the effective height of terrace ridges could be increased by plowing twice in the same furrow for three or four rounds. When a riding plow is used, a deep narrow furrow slice should be moved toward the terrace ridge.

A moldboard designed with the outer end flattened and bent slightly to the rear at a point about 22 inches from the edge of the landside will operate easier along crooked furrows, in soil where sods are frequently encountered, and in soil which tends to stick near the end of a straight moldboard.

The draft of a terracing plow is very similar to that of a general purpose plow when operating under similar conditions.

A plow operating in subsurface soil required about twice as much power as the same plow operating in surface soil.

When terrace ridges are being constructed with a terracing plow, the land should be planted to small grain or some other crop which will cover the surface of the ground and reduce the erosion which may occur from breaks in the low ridges, unless the ridges can be plowed two or three times during the fall or winter in order to increase the effective height. When row crops are grown, the rows should be planted on a contour and parallel with the terrace ridge.

The terracing plow was more useful than a back-filling plow or an ordinary plow in gully control work where soil is removed from the upper edge of a bank in order to establish a more vigorous growth of vegetation in the bottom of the ditch.

THE EFFECT OF DIFFERENT PLANT MATERIALS, LIME, AND FERTILIZERS ON THE ACCUMULATION OF SOIL ORGANIC MATTER[1]

L. M. Turk and C. E. Millar[2]

THAT the soil organic matter affects the chemical, physical, and biological properties of the soil is well known. The effects of added organic matter are usually favorable, but temporary adverse effects may result from the application of large quantities of organic matter having either an extremely narrow or wide carbon-nitrogen ratio. In the former case, toxic concentrations of ammonia or nitrate may accumulate and large losses of nitrogen are apt to result; whereas with an extremely wide ratio, nitrate deficiencies may occur. A desirable balance between carbon and nitrogen must be established before satisfactory crop yields can be expected. A desirable carbon-nitrogen ratio is one which permits the organic matter to decompose with the liberation of just sufficient nitrogen to meet plant requirements.

Long-time experiments[3] show that crop yields can be maintained by the use of mineral fertilizers, including nitrogen, and that at the same time the organic matter content of the soil may be increased. Similar plats receiving organic matter additions yielded no more in spite of the fact that the content of soil organic matter was considerably higher. In other words, soil treatments producing the largest accumulation of organic matter do not necessarily produce the largest yields of crops.

It is logical that the effect of added soil organic matter on crop yield depends upon the predominating effect, i.e., whether chemical, physical, or biological. The common plant nutrients supplied by organic matter may be supplied by fertilizers and when its predominating effect is chemical, fertilizers may effectively replace organic matter. Physically, organic matter increases water retention and fertilizer cannot replace it from this standpoint. Biological activity increases CO_2 production which increases the solubility of minerals and it is therefore tied up with the chemical effect. The "effect" predominating in any case is largely dependent upon the effective climate. Jenny,[4] in discussing the practical aspects of the nitrogen-climate relationship made the following comments: "Concerning this problem of increasing the nitrogen content of the soil by green manuring and similar methods, the nitrogen-climate relationship leads to the following suggestions: It seems to be possible to build up the nitrogen content of cultivated soils in the North by adding organic material because the low temperature would favor its preservation. In southern

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[2]Research Assistant and Head of Department, respectively.

[3]Thorne, C. E. The function of organic matter in the soil. Jour. Amer. Soc. Agron., *18*:767–793. 1926.

[4]Jenny, H. Study on the influence of climate upon the nitrogen and organic matter content of the soil. Mo. Agr. Exp. Sta. Res. Bul. 152. 1930.

latitudes, however, it will be rather difficult, if not impossible, to increase permanently and profitably the nitrogen content of cultivated soils to the forementioned level (virgin level) by such practices because the high temperature militates against organic nitrogen accumulation by favoring decomposition."

"Recently, the term 'nitrogen turn-over' has been suggested, a term which refers to the amount of nitrogen that may be supplied to crops from rotation to rotation by means of crop residues, green manures, farm manures, and commercial manures. It seems probable that in the southern two-thirds of the United States at least, crop production will be maintained or increased by a control of this nitrogen turn-over rather than by an attempt to maintain the total nitrogen content at a particularly high level."

In the South, with warm, moist soil conditions, chemical and biological influences of organic matter are at a maximum. Under similar conditions the physical effect exerted by organic matter at any one time would not be great due to its small quantity. In the northern states where there are greater organic matter accumulations, its physical effects are more pronounced, and due to a slower rate of decomposition extending over a shorter favorable seasonal period, the chemical and biological effects are less potent. Particularly have the physical effects of soil organic matter been observed in the more sandy soils.

The yields of potatoes, various fruits, and truck crops in Michigan are limited, in general, because of insufficient soil moisture and there appears to be a close relationship between content of soil organic matter and the yield of these crops. Since these crops are grown primarily on the more sandy soils of the state, the problem of soil moisture is one of prime importance, which in turn, raises the question as to the most desirable method of adding organic matter to these soils. The primary object of this investigation was to determine some of the factors which affect building up the organic matter and nitrogen content of the lighter soils of Michigan. Considerable choice may be exercised in selecting green-manure crops (including crop residues) which may be incorporated into the soil, and in addition fertilizer and lime may be used with crop residues if they increase the accumulation of organic matter.

PLAN OF INVESTIGATIONAL WORK

In this experiment crop residues of various kinds and combinations were used, with and without the addition of fertilizer and lime. These materials were added to a Hillsdale sandy loam soil, as shown in Table 1, in 1-gallon jars in the greenhouse. The soils were brought up to a favorable moisture content (about one-third the maximum water-holding capacity) at various, although not regular, intervals throughout the experiment. The organic materials were added on the basis of air-dry weight. About 3 inches of stem were included with the alfalfa and sweet clover roots in order to duplicate closely field cutting by machine. Before thoroughly mixing the organic materials with the soil, they were air-dried and ground to a reasonably fine state. The soils were mixed once every 2 months.

Analyses were made for total carbon, total nitrogen, nitrates, and total combustible loss (loss on ignition) at the beginning of the experiment and at the end of each 4-month period thereafter for 2 years. Total carbon was determined by the use of a Fleming combustion furnace and ascarite absorbent; total nitrogen by the Kjeldahl method; nitrates by the reduction method (using Devarda's alloy), and combustible loss by using a muffle furnace. At the end of 2 years the moisture-holding capacities of the soils were determined by the Hilgard cup method and the moisture equivalent determined by the method of Bouyoucos.[5]

RESULTS

The carbon contents of the soils at the beginning of the experiment are shown in Table 1, together with the carbon contents found at other sampling periods. In cases where 20 tons of organic material were added, the original carbon content of the soil was increased approximately 0.7% (column 2) with all the plant materials except muck which increased the carbon supply by almost 0.9%. Muck is largely plant material in an advanced stage of decomposition and it has a realtively high carbon content. The 40-ton application of the various plant materials increased the carbon content of the soils from 1.13 to 1.50%. The values given in Table 1 (column 3) show that significant organic matter decomposition occurred in all soils during the 2-year period, except in the untreated soil and in those soils to which muck alone was applied. The 5% loss of organic matter in the latter case is not significant when compared with the 30 to 40% loss which occurred with most of the other treatments. Relative to the original amount of organic matter in the soil (as measured by combustible loss), there was a greater percentage loss at the end of 2 years in soils to which straw was added alone than in soils to which alfalfa or sweet clover was added alone.

The quantities of organic matter remaining for each soil (relative to the check) are given in Table 1 (column 4). Here again, the slow rate of muck decomposition in contrast to a very rapid disappearance of the other materials is noticed. A better representation of the losses of the added organic matter is presented in column 5. In calculating these values, the quantity of organic matter found in the "check" (no treatment) soil was subtracted from the quantity found in the treated soil both at the beginning and the end of the experiment in each case. With the exception of the muck treatment, less than 32% of the added organic matter remained at the end of 2 years even where 40 tons per acre of dry material were added.

Greater losses occurred with materials of low-nitrogen content which shows the importance of nitrogen in retaining carbon in the soil. This bears out the contention of Russel and Sievers[6] that it is necessary to add nitrogen to soils in order to increase appreciably the

[5]Bouyoucos, G. J. A comparison between the suction method and the centrifuge method for determining the moisture equivalent of soils. Soil Science, 40: 165–170. 1935.

[6]Russel, Sir E. J. Soil Conditions and Plant Growth. New York: Longmans, Green and Co. Ed. 6. 1932. (Pages 364–365.)

Sievers, F. J. Further evidence concerning the significance of nitrogen in soil organic matter relationships. Jour. Amer. Soc. Agron., 22:10–13. 1930.

TABLE 1.—*Carbon and organic matter relationships in soils variously treated.*

Soil treatment*		Total carbon at start %	Combustible loss as % of		Added organic matter left at 24 months %	Total carbon as % of		Added carbon left %		Total carbon as % of original, 20 months	Organic matter, per cent total carbon, end 24 months†
No.	Materials and amounts		Original amount‡	Check		Original amount‡	Check	End of 24 months	End of 4 months		
1	No treatment	1.08	101	100	—	94	100	—	—	96	—
2	20 tons straw	1.78	66	113	18	67	117	25	41	67	1.72
3	20 tons alfalfa roots	1.69	70	121	29	75	125	41	64	76	1.91
4	20 tons muck	1.87	95	152	86	98	180	103	99	99	1.49
5	20 tons sweet clover plants	1.73	68	117	23	72	122	34	43	72	1.74
6	20 tons straw+500 lbs. $(NH_4)_2SO_4$	1.77	66	115	20	67	118	26	40	68	1.94
7	20 tons straw+500 lbs. $CaCN_2$	1.78	67	114	20	68	119	27	44	70	1.74
8	20 tons straw+20 tons alfalfa roots	2.45	59	135	27	56	136	27	43	57	2.24
9	10 tons straw+10 tons alfalfa roots	1.74	69	113	20	70	119	29	41	71	1.60
10	20 tons straw+20 tons muck	2.58	72	170	51	75	192	62	68	76	1.75
11	10 tons straw+10 tons muck	1.77	84	138	58	85	149	71	95	86	1.81
12	20 tons straw+20 tons sweet clover tops	2.21	59	138	28	65	142	37	51	66	2.10
13	20 tons alfalfa roots+3 tons lime	1.67	68	118	24	76	125	43	55	77	1.66
14	20 tons sweet clover plants+3 tons lime	1.76	67	114	20	70	121	32	42	72	1.54
15	20 tons straw+20 tons alfalfa roots +3 tons lime	2.46	54	131	21	58	141	30	55	59	1.75
16	10 tons straw+10 tons alfalfa roots +3 tons lime	1.72	65	117	21	71	120	32	51	72	1.98
17	20 tons alfalfa plants+3 tons lime	1.70	72	121	31	73	121	35	56	73	2.29

*Treatments represent rates per acre.
†Quantities found in check deducted in each case.
‡"Original amount" refers to the quantities originally present after making the soil treatments.

organic matter content. It is obvious, however, that inorganic nitrogen additions will not increase organic matter content unless accompanied by carbon.

Nitrogen fertilizer added to straw increased the accumulation of organic matter and carbon slightly. Since the quantity of nitrogen added with the straw was so small, measurable differences could hardly be expected. In most cases lime increased decomposition considerably, except in the case of the 10-ton application of straw plus the 10-ton application of alfalfa roots (treatments Nos. 9 and 16, column 5, Table 1). Total conbustible loss is not an absolute measure of the quantity of organic matter in the soil, but in this experiment one soil was used throughout and the results are therefore comparable to those of the total carbon method as is shown in columns 3, 4, 6, and 7 of Table 1. There are significant differences in the quantity of organic matter remaining, however, as revealed by the two methods (comparing values in columns 5 and 8). Soil treatment No. 3, for example, shows 29% of added organic matter present (column 5) as measured by total combustion, whereas 41% of the carbon was present (column 8). Treatment No. 17 had 31% of the added organic matter and 35% of the added carbon at the end of 2 years. When the carbon-organic matter factors are calculated from the carbon and organic matter remaining from the plant materials, they are found to vary from 1.49 to 2.29 (column 11, Table 1), which indicates the futility in ascribing any one value to a so-called carbon-organic matter ratio. A much more reliable expression is carbon.

The question may be raised as to whether the differences (column 11, Table 1) will persist for any great length of time. As time goes on the ratios will tend to reach the same value, but the process is slow. The organic matter in the soils in this investigation was decomposing very slowly after 2 years, as may be readily observed by comparing the data presented in columns 6 and 10 of Table 1. Very little decomposition occurred during the last 4 months of the test period which shows that the added organic materials had arrived at a rather stable state. Immediately following organic matter additions to the soil, a very rapid loss of carbon occurred in the presence of favorable environmental factors (column 9, Table 1). In several instances nearly 60% of added carbon disappeared within 4 months.

The carbon-nitrogen relationships in these soils as they existed at the beginning and at the end of the experiment are shown in Table 2. The data in column 2 show the percentage of total nitrogen in each soil at the start, while column 3 shows the quantities of nitrogen, expressed as milligrams per 100 grams of dry soil, gained or lost during the 2 years. In arriving at the latter values the accumulation of nitrate nitrogen was taken into consideration. The gains and losses of nitrogen are insignificant except for treatments Nos. 4 and 14 in which a loss of 12.0 and 16.6 milligrams occurred, respectively; and for treatments Nos. 12 and 17 in which a gain in nitrogen of 11.3 and 15.9 milligrams occurred, respectively. No explanation can be offered for these differences. The other differences are within the experimental error of the total nitrogen determinations. On the whole, these results do not show that significant quantities of nitrogen were fixed by non-

TABLE 2.—*Carbon and nitrogen relationships in soils variously treated.*

Soil treatment*		Total nitrogen at start %	Gain or loss in nitrogen, mgms per 100 grams soil†	Total nitrogen as % of‡		C:N ratio at start	C:N ratio at end of 24 months	C:N ratio relative to ratio at start
No.	*Materials and amounts*			Original amount§	Check			
1	No treatment	0.081	+0.4	96	100	12.7	13.1	103
2	20 tons straw	0.098	—0.2	92	116	17.6	13.2	75
3	20 tons alfalfa roots	0.128	+1.3	89	147	12.9	11.1	86
4	20 tons muck	0.132	—12.0	89	152	13.8	15.6	113
5	20 tons sweet clover plants	0.126	+3.4	85	138	13.4	11.6	87
6	20 tons straw+500 lbs. $(NH_4)_2SO_4$	0.101	+0.3	94	123	17.0	12.6	74
7	20 tons straw+500 lbs. $CaCN_2$	0.098	—1.3	93	119	17.5	13.1	75
8	20 tons straw+20 tons alfalfa roots	0.141	—1.2	86	156	17.0	11.4	67
9	10 tons straw+10 tons alfalfa roots	0.113	—1.6	90	132	14.9	11.8	79
10	20 tons straw+20 tons muck	0.141	+0.1	93	170	18.0	14.8	82
11	10 tons straw+10 tons muck	0.114	—2.1	92	135	15.1	14.4	95
12	20 tons straw+20 tons sweet clover tops	0.137	+11.3	90	159	15.7	11.6	74
13	20 tons alfalfa roots+3 tons lime	0.126	+4.8	86	140	12.9	11.7	91
14	20 tons sweet clover plants+3 tons lime	0.131	—16.6	78	131	13.1	12.1	92
15	20 tons straw+20 tons alfalfa roots+3 tons lime	0.138	—0.1	89	159	17.3	11.6	67
16	10 tons straw+10 tons alfalfa roots+3 tons lime	0.112	+5.0	91	132	14.8	11.9	80
17	20 tons alfalfa plants+3 tons lime	0.123	+15.9	90	143	13.4	11.1	83

*Treatments represent rates per acre.
†Gain or loss in total nitrogen in 24 months, as accounted for in total nitrogen analyses and nitrate determinations.
‡This does not include nitrate nitrogen.
§See footnote on "original amount", Table 1.

symbiotic organisms. If such fixation did occur, it was offset by losses due to volatilization.

The data in columns 6 and 7 (Table 2) show that the carbon-nitrogen ratio of each soil has become more narrow except in the untreated soil and the soil to which muck alone was added. The ratios were wider in soils receiving an application of lime than in the corresponding unlimed soils. The ratio in each case was narrowed to a value equal to or below that of the check soil except in soils treated with muck alone or in combination with other organic residues and soils in which straw was used alone. In cases where 20 tons of organic material were added, it is observed that the greatest percentage change (decrease) in carbon-nitrogen ratio occurred with low-nitrogen material (straw). However, the more narrow ratios were found with treatments of a high-nitrogen (leguminous) material. The soil to which muck was added did not show a more narrow ratio at the end of 2 years than at the beginning because the muck had undergone very little decomposition. In general, carbon was lost from these soils at a much more rapid rate than the transformation of organic to mineral nitrogen occurred and the total loss of carbon was inversely proportional to the original nitrogen content of the added organic matter. There was, however, a decided decrease in organic nitrogen in each soil (column 4, Table 2) with a corresponding increase of nitrate nitrogen.

The nitrate content of each soil at 4-month intervals is presented in Table 3. Generally speaking, the nitrate content of the soils did not increase greatly after 8 months. In some instances there were decreases after that period. Lime did not show a consistent effect on the accumulation of nitrates. When lime was used with sweet clover, the nitrate level was lower at every sampling than where it was omitted. (Compare treatments Nos. 5 and 14.) The reverse was found where alfalfa roots were added except at the end of 8 months (treatments Nos. 3 and 13). Of particular interest is the much greater accumulation of nitrates following addition of straw than of muck. In the soil to which 20 tons of muck were added with 20 tons of straw the accumulation of nitrates was only slightly greater than in the case where 20 tons of straw were used alone. There were more nitrates in the "check" soil at the last two sampling dates than in the soil to which muck alone was added. The lower nitrate content where straw was added with leguminous materials indicates a nitrate tie-up. The nitrates accumulated at a slower rate where the straw was added with the legume. (Compare treatments Nos. 3 and 8 and 5 and 12.) A more pronounced effect no doubt would have been obtained had samples been taken at an earlier period. Ammonium sulfate added with straw increased nitrate accumulation but calcium cyanamide did not.

The amount of organic matter accumulating in any particular soil was greatly influenced by the nitrogen content of the organic material added. In general, those materials with the higher nitrogen content resulted in a greater organic matter accumulation accompanied by a greater release of nitrates.

TABLE 3.—*Nitrate accumulation in soils receiving organic matter, nitrogen fertilizer, and lime treatments.*

Soil treatment*		Milligrams of nitrate nitrogen per 100 grams of oven-dry soil†					
No.	Materials and amounts	4 months	8 months	12 months	16 months	20 months	24 months
1	No treatment	2.2	7.6	4.4	3.8	7.2	6.8
2	20 tons straw	4.2	6.0	7.0	9.6	11.8	9.8
3	20 tons alfalfa roots	13.6	23.4	21.8	21.0	19.2	18.6
4	20 tons muck	6.4	7.6	6.8	4.6	4.8	5.6
5	20 tons sweet clover plants	15.4	23.4	22.0	24.6	28.2	25.4
6	20 tons straw + 500 lbs. $(NH_4)_2SO_4$	6.0	8.8	9.8	13.0	13.0	11.2
7	20 tons straw + 500 lbs. $CaCN_2$	2.2	6.4	7.8	7.0	10.6	8.2
8	20 tons straw + 20 tons alfalfa roots	10.6	18.0	19.6	23.2	26.2	21.6
9	10 tons straw + 10 tons alfalfa roots	7.2	11.8	16.8	16.6	12.0	12.4
10	20 tons straw + 20 tons muck	3.0	6.0	8.2	10.6	12.0	12.4
11	10 tons straw + 10 tons muck	3.6	7.2	7.6	9.2	11.2	10.4
12	20 tons straw + 20 tons sweet clover tops	13.2	19.8	25.2	28.6	32.4	28.2
13	20 tons alfalfa roots + 3 tons lime	18.4	22.0	23.8	26.8	28.2	25.4
14	20 tons sweet clover plants + 3 tons lime	14.8	19.8	18.2	17.8	17.4	15.8
15	20 tons straw + 20 tons alfalfa roots + 3 tons lime	11.8	16.8	20.6	17.2	19.0	18.4
16	10 tons straw + 10 tons alfalfa roots + 3 tons lime	8.8	13.8	15.4	16.2	19.6	18.4
17	20 tons alfalfa plants + 3 tons lime	18.0	25.2	24.2	26.8	29.2	31.6

*Treatments represent rates per acre.
†The soil used contained 3.0 mgms of nitrate nitrogen per 100 grams oven-dry soil.

The importance of organic matter in the soil is not limited to its chemical and biological effects for it also exerts important physical effects. Its effect on the water-retaining capacity of some soils may be its greatest attribute. Moisture data in relation to the amount and kind of soil organic matter in the soils under investigation are shown in Table 4. At the end of 24 months the "no treatment" soil had a moisture-holding capacity of 27.1%, a moisture equivalent of 12.2%, and 0.71% hygroscopic water. The corresponding values for the treated soils relative to the "check" are shown in Table 4 (columns 2, 3, and 4).

In columns 7 and 8 of Table 4 are shown calculated values for the amount of water retained per gram of accumulated organic matter. In arriving at these values combustible loss was taken as organic matter. This is justified since the value for combustible loss for the check was subtracted from each treated soil. Likewise, the value for moisture retained in untreated soil was deducted from values obtained for treated soils. It is of particular interest to note the relatively large amount (2.6 to 19.3 grams) of water retained by the soil per gram of accumulated organic matter (accumulated from that which was added).

The data presented in Table 4 show that organic matter markedly affects the water-holding capacity of the soil. It is assumed that such differences in water retention mean corresponding increases in available water for plant utilization. This assumption is perhaps correct providing the added organic matter does not enhance evaporation. In order to determine the effect of organic matter on the loss of water due to evaporation, the following simple experiment was performed. Water equivalent to the maximum water-holding capacity of each soil was added to a series of Erlenmeyer flasks (125 cc capacity) and 100 grams of soil added to its proper flask. The soil was introduced slowly through a funnel after which the contents of the flasks were slightly tamped to eliminate air pockets. The flasks were left open in the laboratory and weighed at intervals varying from 1 to 7 days to determine loss of water by evaporation. The absolute amount of water lost by evaporation from determination to determination was about the same in all cases. Evaporation per 24 hours was no greater during the first few days. There was no indication that, in those flasks to which organic matter was added, evaporation losses increased even though the water content was greater. Evaporation was allowed to continue for 50 days and there was no apparent decrease in relative rate of loss for the different treatments during that period. The samples were then placed in an oven at 110° C for a period of 24 hours. The percentage of added water that was retained by each soil at the end of 50 days is shown in column 9 of Table 4. The check soil lost a much greater proportion of the added water than did the treated soils. If the above-mentioned soil organic matter-moisture relationships hold under field conditions their practical significance is obvious.

In order to determine the relationship existing between certain moisture values and organic matter, and between total carbon and organic matter of these soils, correlation coefficients were calculated.

TABLE 4.—*Moisture-retaining power of soils as affected by organic matter.*

Soil treatment*		Water-holding capacity†	Moisture equivalent‡	Hygroscopic moisture§	Total carbon as % of check	Combustible loss as % of check	Grams H_2O held per gram of organic matter‖		Per cent of added water retained after 50 days
No.	Materials and amounts						Hilgard cup method	Moisture equivalent	
1	No treatment	100	100	100	100	100	—	—	39.6
2	20 tons straw	111	117	105	117	113	10.0	7.0	50.2
3	20 tons alfalfa roots	110	118	112	125	121	5.6	4.6	51.5
4	20 tons muck	116	120	150	180	152	2.6	2.0	53.9
5	20 tons sweet clover plants	120	122	114	122	117	13.5	6.9	50.3
6	20 tons straw + 500 lbs. $(NH_4)_2SO_4$	116	119	110	118	115	12.2	6.5	49.3
7	20 tons straw + 500 lbs. $CaCN_2$	115	122	104	119	114	12.4	8.1	50.2
8	20 tons straw + 20 tons alfalfa roots	136	141	121	136	135	11.9	6.0	54.8
9	10 tons straw + 10 tons alfalfa roots	109	123	107	119	113	6.7	9.0	49.7
10	20 tons straw + 20 tons muck	137	155	155	192	170	6.0	4.0	52.7
11	10 tons straw + 10 tons muck	111	129	127	149	138	3.2	3.8	53.3
12	20 tons straw + 20 tons sweet clover tops	151	152	124	142	138	15.6	7.0	55.8
13	20 tons alfalfa roots + 3 tons lime	125	132	116	125	118	15.9	9.2	51.1
14	20 tons sweet lcover plants + 3 tons lime	118	139	113	121	114	15.1	14.2	50.7
15	20 tons straw + 20 tons alfalfa roots + 3 tons lime	152	155	126	141	131	19.3	9.1	58.9
16	10 tons straw + 10 tons alfalfa roots + 3 tons lime	127	120	112	120	117	18.2	6.2	53.2
17	20 tons alfalfa roots + 3 tons lime	121	127	115	121	121	11.2	6.6	54.8

*Treatments represent rates per acre.
†Hilgard cup method.
‡Bouyoucos method.
§Air-dried soils placed in oven at 110° C for 12 hours.
‖Data for combustible loss were used and values for check were subtracted from treated soils (24 months).

These data are shown in Table 5 and are presented graphically in Figs. 1 and 2. In making these calculations the soils to which muck was added were omitted.

TABLE 5.—*Interrelationships of carbon, organic matter, and certain moisture values.*

Factors correlated	Correlation coefficient	Number of comparisons
Total carbon and combustible loss	.964* ± .0196†	14
Water-holding capacity and combustible loss	.883 ± .0611	14
Increase in water-holding capacity and increase in organic matter	.863 ± .0737	13
Water-holding capacity and hygroscopic water	.919 ± .0431	14
Water-holding capacity and moisture equivalent	.900 ± .0527	14
Moisture equivalent and hygroscopic water	.872 ± .0665	14

*Corrected for small number of cases.
†Standard error.

It is obvious from an inspection of the data given in Table 5 that a very close relationship exists in this particular soil, variously treated, between total carbon and combustible loss and between water-holding capacity and combustible loss. When these factors are correlated, correlation coefficients are obtained that are highly significant statistically. A correlation coefficient of .863±.0737 is obtained when increase in water-holding capacity is correlated with increase in organic matter. It is of interest to note the high degree of correlation existing between the three forms (or moisture values) of soil water for this particular soil. For example, a correlation coefficient of .900±.0527 is obtained by correlating water-holding capacity and moisture equivalent, a similar correlation coefficient for water-holding capacity and hygroscopic water, and also for moisture equivalent and hygroscopic water. Since moisture determinations by either of the above-mentioned methods are arbitrary and only relative at best, it would seem from the results here reported that the three moisture determinations yield results of about equal value. In other words, just as good an idea of a soil's ability to hold water can be obtained with the Hilgard cup as with the moisture equivalent method or the determination of hygroscopic water. It is not to be inferred that the relationships indicated for this soil will necessarily hold for soils in general.

DISCUSSION AND SUMMARY

Several investigations show that the nitrogen content of a soil tends to come to equilibrium at a point that depends upon the effective climate and the cropping system as it effects organic matter additions. Soils in their natural state, where there is sufficient rainfall, are covered with a mat of decomposing grass or leaves. Cultivation dis-

turbs this condition and increases the rate of decay of the organic matter.

In general farming practices it is logical to place more emphasis on the activity of the organic matter rather than to attempt to raise it to a high level by the use of organic manures and fertilizers. Certain intensive crops, however, may demand a uniform water supply which

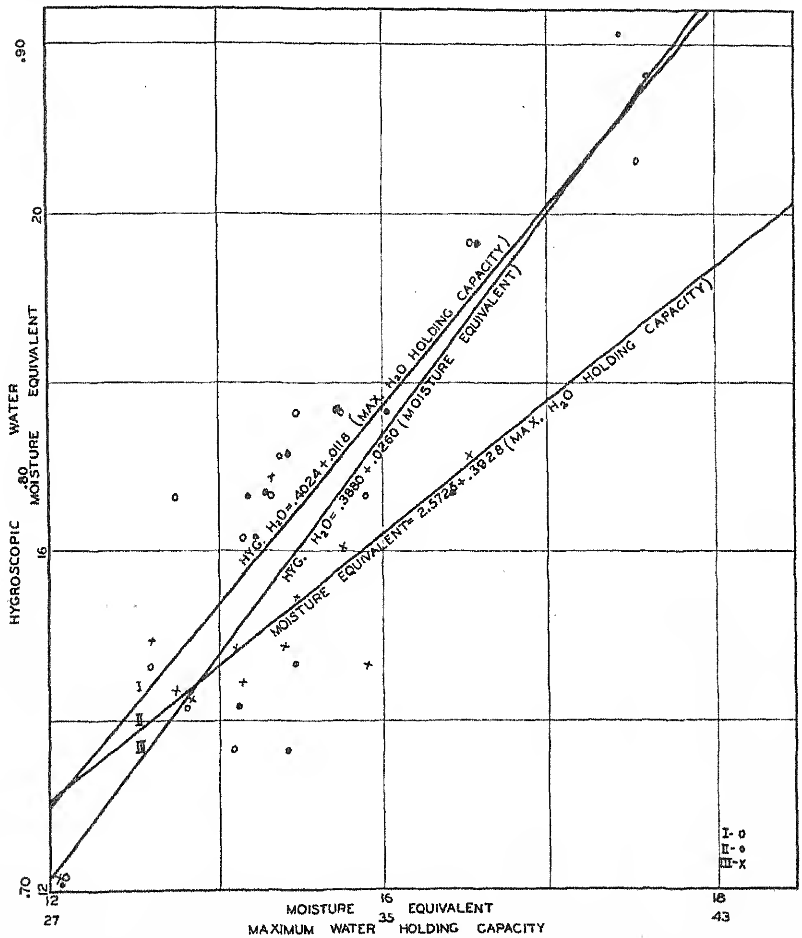

FIG. 1.—Interrelationship of certain moisture values (hygroscopic water, moisture equivalent, and maximum water-holding capacity) in soil containing different amounts of organic matter.

a high organic matter level helps to maintain. Under these conditions building up the soil organic matter above its natural level may be profitable.

The results of the investigations here reported show that materials with a wide carbon-nitrogen ratio lost a larger percentage of their carbon than those with a narrower ratio. A loss of 69% or more of the

added organic matter occurred in 2 years in every soil except that to which muck was added. Most of this loss occurred during the first 4

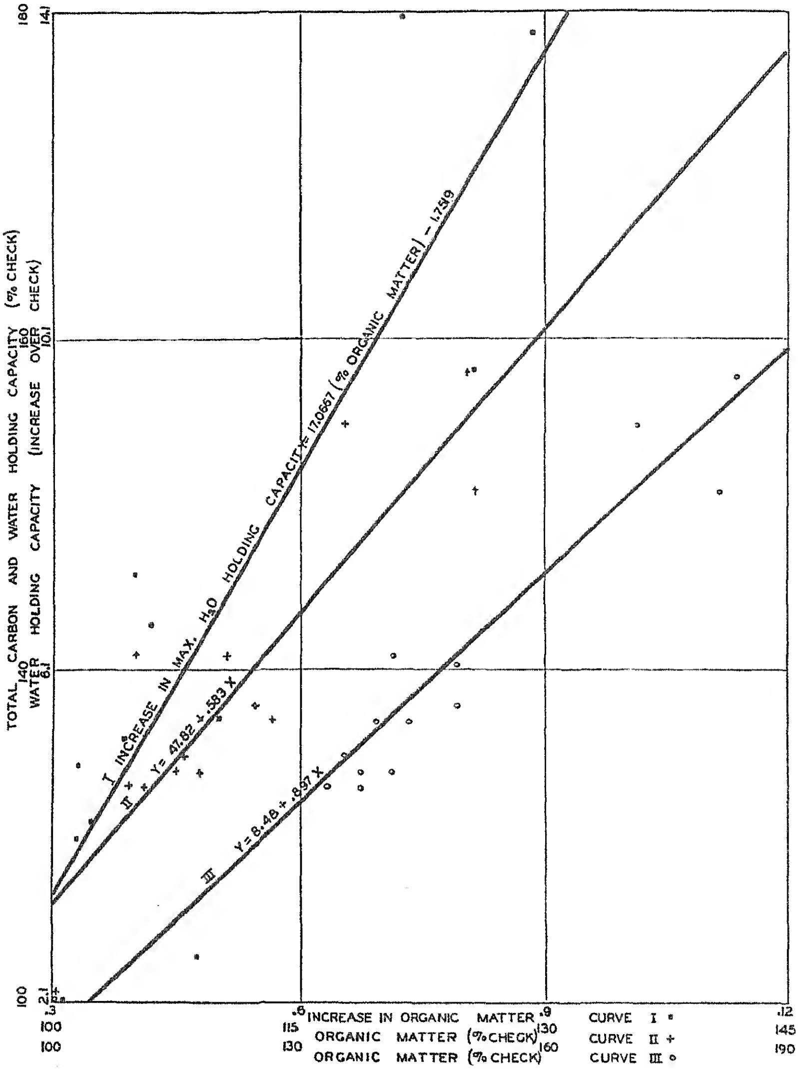

FIG. 2.—Relationship between increase in maximum water-holding capacity and increase in organic matter (curve I), water-holding capacity and total organic matter (curve II, values expressed relative to "check"), and carbon and total organic matter (curve III, values expressed relative to "check").

months of the study. Since the experiment was set up in the greenhouse, decomposition proceeded faster than it does under most field conditions due to the higher temperature, but the same relative differences in the variously treated soils would probably be obtained in

the field. Only 25% of the carbon and 18% of the organic matter added in the form of straw applied at the rate of 20 tons of dry material per acre remained in the soil at the end of 2 years. Had the soil been growing a crop which would have utilized some of the nitrogen the results doubtless would have been lower. This shows the futility of attempting to build up soil organic matter by turning under straw or other low-nitrogen materials.

The addition of $(NH_4)_2SO_4$ to straw resulted in the accumulation of more organic matter, although the increase was not great. Theoretically, the quantity of nitrogen fertilizers applied in this experiment will not give large differences in the resulting organic matter, because only the equivalent of a 500-pound per acre application of $(NH_4)_2SO_4$ was used. One gram of $(NH_4)_2SO_4$ contains 0.2 gram of nitrogen. This quantity of nitrogen could fix only about 2.4 grams of carbon, assuming a carbon-nitrogen ratio of 12:1. If this quantity were so fixed, it would increase the carbon content of the soil only 0.06%. Since 81.5 grams of straw with a nitrogen content of 0.75% was added to 4,000 grams of soil, only 0.61 gram of nitrogen was added. This quantity of nitrogen could theoretically fix 7.33 grams of carbon. Therefore, 9.73 grams (7.33 plus 2.4) is the total quantity of carbon that could be fixed by both the nitrogen of the $(NH_4)_2SO_4$ and the nitrogen of the straw. This quantity of carbon (9.73 grams) should give an increase in the soil of 0.243% carbon, assuming all the nitrogen is active in holding carbon. The actual difference in carbon between this and the check soil as found by analysis, was 0.18%, which is not far from the theoretical value. It is interesting to note in this connection that there was more nitrate nitrogen in the treated than in the untreated soil (Table 3), which, of course, was not holding carbon.

Thirty-five per cent of the added carbon in the alfalfa plants and 34% in the sweet clover plants remained in the soil at the end of 2 years, whereas only 25% of that of the straw was present at that time. This shows that the nitrogenous materials are of much greater value for increasing the organic matter of the soil than are carbonaceous materials and that at the same time they release more nitrogen for plant use.

The carbon-nitrogen ratio of each soil became more narrow except in the untreated soil and in the one to which muck was added alone. The ratios were narrowed to or below that of the check in every instance except where muck was used. Since muck is largely plant material in an advanced stage of decomposition, its ratio of carbon to nitrogen did not change much during a 2-year period after being added to a mineral soil. Those soil treatments having the more narrow carbon-nitrogen ratios at the beginning of the experiment did not possess the more narrow ratios at the end. It is the opinion of the writers that the carbon-nitrogen ratios would have become more narrow if the nitrates had been removed as occurs under field conditions.

Large quantities of nitrates accumulated with all treatments. The greatest accumulation of nitrates occurred with the additions of leguminous materials, while the smallest accumulations followed

additions of muck and straw. The low quantity of nitrates present in the muck-treated soil at the end of the experiment is in agreement with its slow rate of loss of carbon or its slow decomposition.

In most cases lime did not show any consistent effect on the quantity of nitrates accumulated (original soil had a pH of 5.5). Straw added with leguminous materials delayed the accumulation of nitrate nitrogen and under field conditions this would decrease leaching losses of nitrate nitrogen. The results show that under conditions where organic matter of a wide carbon-nitrogen ratio is plowed under, as for example straw, a treatment with a nitrogen fertilizer will overcome the depressing influence on nitrate accumulation and will also tend to retain more of the organic matter or carbon in the soil.

In most cases lime increased organic matter decomposition, as would be expected in an acid soil. Under field conditions, the increased crop residue obtained with the use of lime will off-set the increase in the rate of decomposition of the soil organic matter occasioned by the lime.

A high correlation coefficient was found when differences (increases over check) in soil organic matter were correlated with differences (increases over check) in water-holding capacity.

Since soil miosture is, in general, the greatest limiting factor in the production of potatoes, and of many fruit and truck crops, on the sandy soils of Michigan, it would seem logical and economical from the results reported herein to add large quantities of organic material to these soils for the main purpose of increasing their water retentiveness. The leguminous or more nitrogenous materials are most effective for this purpose, while straw and similar carbonaceous material supplemented with liberal applications of commercial nitrogen may also be used.

NOTES

INHERITANCE OF SEEDLING STEM COLOR IN A BROOMCORN-SORGHUM CROSS

INHERITANCE of seedling stem color in a number of crosses between different types of grain sorghums was worked out and reported by Reed.[1] Certain grain sorghums, as Red Amber Sorgo, Sumac Sorgo, Durra, and Milo, had red seedlings, and in certain others, as Dawn, Kafir, Feterita, Shallu, and Black Amber Sorgo, the seedlings were green. In inheritance, red was dominant to green and in F_2 a ratio of 3 red to 1 green was obtained.

During the course of certain preliminary studies on broomcorn at the Illinois Agricultural Experiment Station, a planting was made of the F_2 generation of a cross between Shallu, a grain sorghum, and Black Spanish broomcorn. The seed was kindly furnished by Dr. John Martin, Sorghum Investigations, Bureau of Plant Industry, U. S. Dept. of Agriculture, the cross having been made by him and the F_1 generation grown at Arlington Farm.

When the F_2 seedlings were 2 or 3 inches tall, it was observed that they were segregating for stem color. Counts were made in one row before any thinning was done. Of a total of 336 seedlings, 194 had red stems and 142 had green stems. This at once suggested a 9:7 ratio of red to green. On the basis of this ratio, the expected numbers would be 189 red to 147 green, a deviation of 5 from expectation.

At thinning, all the green-stemmed seedlings were removed from the row on which the above counts were made, leaving only the red-stemmed to develop. In the fall the heads were harvested from each F_2 plant in this row, hung up to dry, threshed, and a portion of the seed of each planted in a sand bench in the greenhouse for counts on stem color. The results are given in Table 1.

On the assumption of two genes, both of which must be present to produce red, there should be three types of F_2 red-stemmed plants on the basis of breeding behavior. These types are as follows: (1) Breed true for red, (2) segregate for red and green in a 3:1 ratio, and (3) segregate for red and green in a 9:7 ratio; and these types should occur in the ratio of 1:4:4.

That these expectations were realized, in the main, is evident from a study of the data in Table 1. All three types were obtained and in approximately the expected ratio. Of 126 plants tested, 13 bred true for red, 70 segregated in a 3:1 ratio, and 43 segregated in a 9:7 ratio, the expected numbers on the basis of a 1:4:4 ratio being 14, 56, and 56, respectively. When the X^2 goodness of fit was applied, X^2 was found to be 7.52 and the probability, P, was .024. Hence, on the basis of random sampling, a worse result might be expected 24 times in 1,000 trials or once in 42 trials.

Some difficulty was experienced with a few F_3 families in determining whether the segregation ratio was 3:1 or 9:7, and there may be a few errors on that account. However, in all doubtful cases, the prob-

[1] REED, GEORGE M. A new method of production and detecting sorghum hybrids. Jour. Heredity, 21:133–144. 1930.

TABLE 1.—*Breeding behavior in F_3 of red-stemmed F_2 plants of a broomcorn-sorghum hybrid with respect to seedling stem color.*

Plant	Red	Green	Total	Type of segregation	Plant	Red	Green	Total	Type of segregation
1	32	12	44	3:1	47	107	31	138	3:1
2	44	23	67	9:7	48	40	22	62	9:7
3	98	35	133	3:1	49	53	28	81	9:7
4	35	22	57	9:7	50	71	37	108	9:7
5	113	39	152	3:1	51	42	6	48	3:1
6	54	45	99	9:7	52	23	15	38	9:7
7	43	16	59	3:1	53	33	17	50	9:7
8	80	30	110	3:1	54	55	22	77	3:1
9	103	31	134	3:1	55	23	9	32	3:1
10	129	46	175	3:1	56	18	18	36	9:7
11	72	54	126	9:7	57	43	25	68	9:7
12	69	5	74	3:1	58	39	18	57	3:1
13	55	9	64	3:1	59	48	19	67	3:1
14	115	39	154	3:1	60	146	28	174	3:1
15	66	18	84	3:1	61	70	34	104	3:1
16	54	30	84	9:7	62	72	35	107	3:1
17	39	21	60	9:7	63	9	0	—	Bred true
18	95	42	137	3:1	64	59	19	78	3:1
19	148	102	250	9:7	65	82	18	100	3:1
20	164	41	205	3:1	66	87	29	116	3:1
21	118	29	147	3:1	67	49	28	77	9:7
23	129	37	166	3:1	68	20	6	26	3:1
24	82	24	106	3:1	69	34	14	48	3:1
25	132	50	182	3:1	70	67	21	88	3:1
26	115	39	154	3:1	71	182	166	348	9:7
27	94	39	133	3:1	72	81	33	114	3:1
28	104	39	143	3:1	73	86	37	123	3:1
29	139	43	182	3:1	74	90	22	112	3:1
30	65	40	105	9:7	75	43	16	59	3:1
31	70	56	126	9:7	76	72	39	111	9:7
32	110	25	135	3:1	77	68	8	76	3:1
33	116	48	164	3:1	78	57	21	78	3:1
34	38	27	65	9:7	80	81	43	134	3:1
35	105	50	155	9:7	81	40	37	77	9:7
36	120	0	—	Bred true	82	92	0	—	Bred true
37	95	36	131	3:1	83	55	31	86	9:7
38	75	58	133	9:7	84	29	7	36	3:1
39	181	0	—	Bred true	85	53	27	80	3:1
40	155	0	—	Bred true	86	87	46	133	9:7
41	77	23	100	3:1	87	56	13	69	3:1
42	97	35	132	3:1	88	—	—	—	—
43	96	31	127	3:1	89	73	1	—	Bred true
44	33	5	38	3:1	90	—	—	—	—
45	42	21	63	3:1	91	31	0	—	Bred true
46	146	61	207	3:1	92	72	0	—	Bred true

TABLE 1.—*Continued.*

Plant	Red	Green	Total	Type of segregation	Plant	Red	Green	Total	Type of segregation
93	24	13	37	9:7	114	37	26	63	9:7
94	33	18	51	9:7	115	61	41	102	9:7
95	9	6	15	9:7	116	9	4	13	9:7
96	117	28	145	3:1	117	45	1	—	Bred true
97	109	39	148	3:1	118	11	7	18	9:7
98	120	22	142	3:1	119	21	6	27	3:1
99	7	6	13	9:7	120	43	8	51	3:1
100	131	19	150	3:1	121	115	19	134	3:1
101	—	—	—	—	122	20	14	34	9:7
102	23	13	36	9:7	123	50	22	72	3:1
103	65	62	127	9:7	124	91	21	112	3:1
104	44	0	—	Bred true	125	32	27	59	9:7
105	52	18	70	3:1	126	55	23	78	3:1
106	19	0	—	Bred true	127	41	37	78	9:7
107	53	0	—	Bred true	128	95	34	129	3:1
108	37	6	43	3:1	129	114	60	174	9:7
109	18	0	—	Bred true	130	12	12	24	9:7
110	34	21	55	9:7	131	49	19	68	3:1
112	14	13	27	9:7	132	137	90	227	9:7
113	54	5	59	3:1					

able error was calculated and divided into the deviation from the expected ratio. The size of the quotient thus obtained was used as the determining factor, the ratio with the smaller quotient being chosen to apply to the particular segregating family under consideration.—C. M. WOODWORTH, *Plant Breeding Division, Agronomy Department, Illinois Agricultural Experiment Station, Urbana, Ill.*

THE TERM "RANGE WEED" AS USED BY WESTERN STOCKMEN AND THE U. S. FOREST SERVICE

REFERENCE is made to Dr. Pieters' excellent essay of inquiry, "What is a Weed?" which opens the October, 1935, issue of this JOURNAL. Because of Dr. Pieters' criticism of U. S. Forest Service usage of the term "weed", apparently based, in part, on definitions in my *Glossary of Botanical Terms used in Range Research* (U. S. D. A. Misc. Pub. 110, 1931), and his recommendation that we adopt the term "forb", may I be permitted an opportunity to present certain facts and viewpoints, in order that readers of the JOURNAL may get the full background involved?

Any fair-minded person must admit that Dr. Pieters' theses have much merit and strong arguments to support them, and that it is unfortunate that any word in common usage should have ambiguity resultant from differences in interpretation by diverse groups. I submit, however, that, from the standpoints of historicity and usage, to the Forest Service is not traceable the paternity of the word "weed" *in sensu nomologico*. In the first place, while Dr. Pieters' definition

and comments on the English word "weed" well harmonize with definition "1" of the word in the New English (Oxford) Dictionary—probably the most scholarly and authoritative lexicon of our language extant—yet it also as clearly does not apply to "weed" definitions "b", "c", "e", and "2" of that work. In the second place, numerous, long-established English plant names with "-weed" as a suffix, *e.g.*, bugleweed, ironweed, Joe-pye-weed, pickerelweed, snapweed, and willowweed, exist wherein the "-weed" portion of the name does not at all connote essential undesirability. In the third place (perhaps unfortunately, it is true), "weed" is universally used by western stockmen for nongrasslike herbs. In other words, the Forest Service has had a strong, uniform intrenched field usage to deal with from the start.

It is true that some Forest Service technical men in scientific papers of an ecological nature, have used Dr. Clements' term "forb". Laying aside any question as to form, "forb" is admittedly an Anglicization or free transliteration of the Greek word φορβή, food—especially forage or fodder. Frankly, I gravely doubt if "forb" will ever be adopted by the horny-handed stockman and cowpuncher. He will say to us: "Talk 'United States'"! Furthermore, it seems to me that, from its basic etymology, "forb" cannot properly be a thorough synonym of the range "weed". The stockman's "weed" covers nongrasslike herbs whether palatable, nonpalatable, poisonous, harmless, injurious, desirable, or undesirable—it is a true vegetative *type*. "Forb", irrespective of whether it might not also rightfully include grass, sedges, rushes, and browse, at least in essence connotes palatable, harmless, and desirable species only.

It is Forest Service practice, in publications employing the word "weed" *in the range sense*, to give a definition of the term so that there can be no conflict with the agronomic or agricultural use of the word, and to use the phrase "range weed" as much as possible, so that the reader will be in no doubt as to what is meant. It is, of course, a very fair question whether some other term would not be preferable. Dr. Sampson in his text, *American Native Forage Plants*, invented the phrase "broad-leaved herbs", but that is awkward and often inaccurate and misleading. "Nongrasslike herbs" is also awkward, and too long. Until some bright mind suggests a term on which stockman, range administrator, scientist, farmer, and agronomist will unite, it is my personal feeling that the Forest Service is justified in retaining the phrase "range weed" for its nongrass, nongrasslike, herbaceous range vegetation.—W. A. DAYTON, *Senior Forest Ecologist, in charge, Range Forage Investigations, Division of Range Research, U. S. Forest Service, Washington, D. C.*

AN INTERESTING SEED COMBINATION

EARLY in 1935, the junior writer obtained a commercial sample of oats in which many of the primary grains appeared to have a seed of another plant growing within them. On careful examination it was found that seeds of the Napa thistle (*Centaúrea meliténsis* L.) were lodged on the palea behind the folds of the lemma, thus giving the interesting double seed combination shown in Fig. 1. The thistle seeds probably were deposited at an early stage in the development of the oat lemmas and caryopses. In fact, the thistle seed appeared to have caused depressions in the oat kernels at the points of contact. It is not believed that they could have been deposited so well at later stages in the development of the grain or in the harvesting and threshing operations.

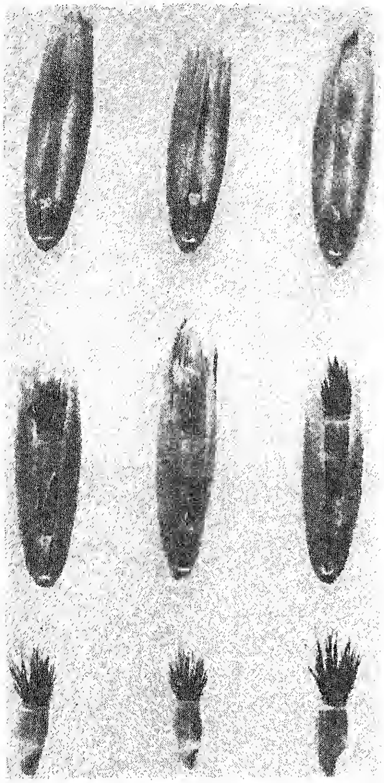

FIG. 1.—Upper row, normal oats; middle row, oat grains with Napa thistle seeds deposited within them; lower row, thistle seeds removed from the oat grains.

These oats had been grown in western Oregon where the Napa thistle is a noxious weed. This variety of thistle matures quite early and may have been shedding its seeds at about the time these oats were flowering. The large pappus of the thistle seeds greatly favor their dissemination by wind. It is said that at time of ripening if the wind happens to be blowing the atmosphere becomes filled with these seeds and that they are carried long distances. In the case of these oats it is possible that a strong wind blew for a few days just at the opportune time, or otherwise the thistle seeds would not have been deposited so precisely within the oat lemmas.

A seed combination of this kind is new to the writers, who have observed and worked with oats from various regions of the United States for many years. Quack and similar seeds, however, are frequently found embedded in grains of commercial oats.

It is not advisable to use for seed any oats that have Napa thistle, quack, or other noxious weed seeds embedded in the grains, as the weed seeds lodged behind the folds of the oat lemma cannot be removed by mechanical means and would, therefore, be planted with

the oats.—T. R. STANTON and E. G. BOERNER, *Division of Cereal Crops and Diseases, Bureau of Plant Industry, and the Grain Division, Bureau of Agricultural Economics, U. S. Dept. of Agriculture.*

LONGEVITY AND VIABILITY OF SORGHUM SEED

RESULTS upon the viability of old sorghum seed were published in the May 1928 number of this JOURNAL. In the course of breeding work with sorghums, seed from numerous selections and hybrids accumulate and the question of how long such remnant seed might be useful and retain its power of germination is an important one. Also, the expectancy, or longevity, before germinability is completely exhausted is of interest as prior to that time even a very low percentage of germination might suffice to recover and renew the stock.

In breeding work with sorghums at the Lubbock, Texas, Substation, seed stock from original selections made in 1917 was preserved. Seed of Blackhul kafir, stored in the laboratory in ordinary seed envelopes and protected from weevil, have been tested for germination at intervals of 1 or 2 years since 1924. Results of these tests were as follows:

Year	%	Year	%
1917	(100)	1931	34.2
1924	88.0	1933	15.5
1926	79.5	1935	4.0
1927	65.0	1936	0.5
1929	48.0		

Theoretically, the viability of this sorghum seed when harvested in 1917 was 100% and, with this assumption, it lost only 12% of its viability in the first 7 years. After 10 years almost half of the seed still retained power of germination, but thereafter it lost its viability quite rapidly until in the nineteenth year only 1 seed grew out of 200 tested. A duplicate test of 200 seeds was made on sterilized agar in 1936 and two seeds succeeded in sending out very weak sprouts. After 1931, it was noted that in each of the tests even the seed that responded with growth in many cases showed only weak germination and lacked the vigorous sprouts commonly found in fresh seed.

Ayyangar and Ayyar, of the Agricultural Research Institute, Coimbatore, India, recently reported that sorghum seed there, when preserved in the head, showed a viability of around 90% for 3 or 4 years, but that in no case did 7-year-old seed germinate. Threshed seed stored in bottles deteriorated to a germination of only 10% after 4 years. Moisture, humidity, and temperature conditions in storage undoubtedly are the important factors affecting the rate of deterioration, and the fact that the seed stored at Lubbock were in a relatively dry region where the humidity is low and high temperatures of short and infrequent occurrence is likely responsible for the slow rate of deterioration.

The graph in Fig. 1 quite clearly illustrates the decline in viability as well as the longevity, or life-span, or sorghum seeds stored under conditions favorable to their retention of germinating powers. It is

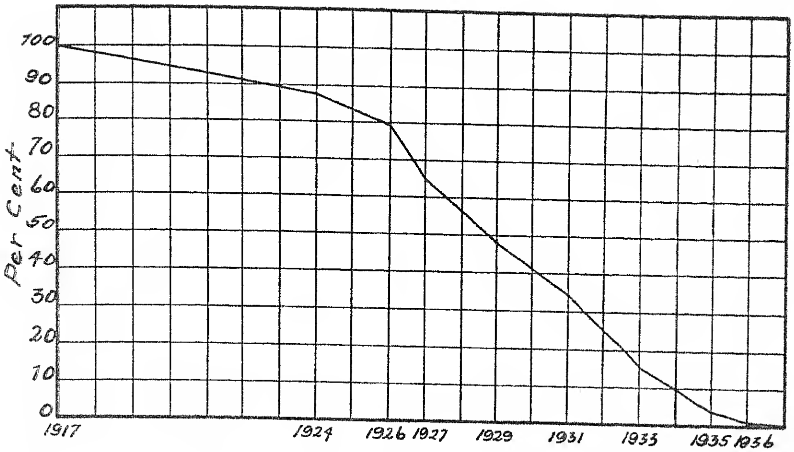

FIG. 1.—Curve showing the decline in the viability of sorghum seed over a 19-year period.

apparent that a smooth curve fitted to these results would closely approach in form the right one-half of a normal frequency curve and may be considered as a "death curve". If the growth curve of a sorghum plant is considered as the other half, and if the two are reduced to relative terms, the complete normal curve will be approached; however, the cycle involved in the growth is 3 to 4 months, whereas that of decline, or death, is approximately 20 years.—R. E. KARPER and D. L. JONES, *Texas Agricultural Experiment Station, College Station, Texas.*

AGRONOMIC AFFAIRS

MEETING OF THE NORTHEASTERN SECTION

THE annual meeting of the Northeastern Section of the Society will be held at the West Virginia Agricultural Experiment Station, Morgantown, W. Va., June 24 to 26. Details of the program will appear in the next issue of the JOURNAL. Professor J. S. Owens, Connecticut Agricultural Experiment Station, Storrs, Conn., is Secretary-Treasurer of the Northeastern Section.

TENTATIVE PROGRAM FOR MEETING OF AMERICAN SOIL SURVEY ASSOCIATION AND SOILS SECTION OF THE AMERICAN SOCIETY OF AGRONOMY

A TENTATIVE program for the 1936 annual meeting of the American Soil Survey Association and of the Soils Section of the American Society of Agronomy to be held in Washington, D. C., is submitted at this early date for its suggestive value. It has not been possible for the various chairmen to announce all the subjects for discussion or to present extensive plans, so these must come at a later date. This program is subject to revision. Other sectional programs may be added and necessary changes may be made in those given. The program is submitted as a general plan for consideration. The various chairmen solicit cooperation with suggested subjects and by means of early announcements regarding contributions to the program.—GEORGE D. SCARSETH, *President, American Soil Survey Association;* and WM. A. ALBRECHT, *Chairman, Soils Section, American Society of Agronomy.*

TUESDAY MORNING

8:00– 9:00 Registration American Soil Survey Association

9:00– 9:15 General Assembly, Announcements, Appointment of Committees

SECTION V.—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

9:15–10:30 Committee on Soil Survey Maps, Reports and Technic of Mapping —T. M. Bushnell, Purdue University, Lafayette, Ind., *Chairman*

10:30–11:30 Committee on Organic and Water Soils—J. O. Veatch, Michigan State College, East Lansing, Mich., *Chairman*

11:30–12:00 Committee on Exchange of Profiles—H. J. Harper, Oklahoma Agricultural College, Stillwater, Okla., *Chairman*

TUESDAY AFTERNOON

SECTION V.—SOIL GENESIS, MORPHOLOGY, AND CARTOGRAPHY

Session A

1:30– 4:00 Committee on Forest Soils—J. T. Auten, Central States Forest Exp. Sta., Columbus, Ohio, *Chairman*

Session B

1:30– 2:30 Committee on Soil Structure—L. D. Baver, University of Missouri, Columbia, Mo., *Chairman*

2:30– 3:15 Committee on Horizon Criteria—E. A. Norton, Soil Conservation Service, Des Moines, Iowa, *Chairman*

3:15– 4:00 Committee on Nomenclature—G. E. Conrey, Ohio Experiment Station, Wooster, Ohio, *Chairman*

4:00– 5:00 Business Meeting American Soil Survey Association—G. W. Scarseth, *Chairman*

Report of the Committee for Drafting a Constitution for the American Society of Soil Science

7:00 P. M. Dinner American Soil Survey Association

WEDNESDAY MORNING

Registration American Society of Agronomy

SECTION I.—SOIL PHYSICS

Submitted and solicited papers—L. D. Baver, University of Missouri, Columbia, Mo., *Chairman*

SECTION IV.—SOIL FERTILITY

Submitted and solicited papers—F. C. Bauer, University of Illinois, Urbana, Ill., *Chairman*

SECTIONS V AND VI.—SOIL MORPHOLOGY AND SOIL SCIENCE APPLIED TO LAND USE

G. D. Scarseth, Alabama Polytechnic Institute, and R. V. Allison, Soil Conservation Service, Washington, D. C., *Co-chairmen*

Committee on Soil Geography—Mark Baldwin, Bureau of Chemistry and Soils, U. S. Dept. Agr., Washington, D. C., *Chairman*

Submitted and solicited papers

Land Classification and Land Use

Submitted and solicited papers

WEDNESDAY AFTERNOON

SECTION II.—SOIL CHEMISTRY

R. H. Bray, University of Illinois, Urbana, Ill., *Chairman*

Committee on Processes and Products of Soil Weathering—M. S. Anderson, Bureau of Chemistry and Soils, U. S. Dept. Agr., Washington, D. C., *Chairman*

Submitted and solicited papers

Symposium: What Constitutes Availability of the Essential Elements in the Soil?

Submitted and solicited papers

SECTION IV.—SOIL FERTILITY

F. C. Bauer, University of Illinois, Urbana, Ill., *Chairman*

Submitted and solicited papers

SECTION VI.—SOIL SCIENCE APPLIED TO LAND USE

R. V. Allison, Soil Conservation Service, Washington, D. C., *Chairman*

Committee on Soil Conservation—J. G. Hutton, Soil Conservation Service, Huron, S. D., *Chairman*

WEDNESDAY EVENING

Special business meetings of the American Society of Soil Science and of the International Society of Soil Science

THURSDAY MORNING

General Program American Society of Agronomy—R. M. Salter, Ohio Experiment Station, Wooster, Ohio, *Chairman*
Subjects and speakers to be announced

THURSDAY NOON

Luncheon Conference Legume Inoculants, Inspection, Production, and Tests

THURSDAY AFTERNOON

Program American Society of Soil Science—G. D. Scarseth and Wm. A. Albrecht, *Co-chairmen*
Soil Science as Related to Other Sciences
Subjects and speakers to be announced

THURSDAY EVENING

Annual Dinner American Society of Agronomy
Presidential address, reports, and awards

FRIDAY MORNING

SECTION II.—SOIL CHEMISTRY

R. H. Bray, University of Illinois, Urbana, Ill., *Chairman*
Submitted and solicited papers

SECTION III.—SOIL MICROBIOLOGY

J. K. Wilson, Cornell University, Ithaca, N. Y., *Chairman*
Symposium: Interrelationships Between Plant Pathogens and Saprophites in the Soil Population
Submitted and solicited papers

SECTION IV.—SOIL FERTILITY IN JOINT SESSION WITH CROPS SECTION

M. T. Jenkins and F. C. Bauer, *Co-chairmen*
Symposium: Newer Developments in Experimental Design
Submitted and solicited papers

FRIDAY AFTERNOON

SECTION III.—SOIL MICROBIOLOGY

J. K. Wilson, Cornell University, Ithaca, N. Y., *Chairman*
Submitted and solicited papers

SECTION VI.—SOIL SCIENCE APPLIED TO LAND USE

R. V. Allison, Soil Conservation Service, Washington, D. C., *Chairman*
Submitted and solicited papers

THE CROPS SECTION PROGRAM

TENTATIVE plans are being formulated for the Crops Section meetings at the annual meeting of the Society in Washington next November. It is proposed that a 3-day program be developed as follows: *Wednesday*, programs dealing with more technical subjects such as genetics and physiology of crop plants, and round-table discussions on special topics; *Thursday morning*, general program of the American Society of Agronomy; *Thursday afternoon*, programs on plant breeding, crops extension, and pasture management; *Friday*, programs on general phases of crops research, probably including a special program on southern field crops, and a joint symposium with the Soils Section on "Newer Developments in Deisgn of Field Experiments." A symposium on soybeans has been requested, and other programs may be developed if sufficient interest is expressed.

The purpose of this preliminary announcement is to indicate the intention of coordinating the crops meetings with those of the Soils Section. The more technical programs of each section are to be scheduled for the early part of the meetings, and the more general phases for the latter part. This will permit those interested in both phases of agronomy to attend general programs on either soils or crops during the last day of the meeting. Further details will be provided later.—H. B. SPRAGUE, *Chairman, Crops Section.*

NEWS ITEMS

Dr. N. A. PETTINGER, Associate Agronomist of the Virginia Polytechnic Institute, died in the Roanoke Hospital, Roanoke, Virginia, on February 1, 1936. He had been confined to his bed with a heart trouble for the previous eight months. Dr. Pettinger came to Virginia after having obtained the Ph.D. degree at the University of Illinois in 1927. He was in charge of soils teaching and research for the Virginia Polytechnic Institute and Virginia Agricultural Experiment Station.

Dr. H. K. HAYES, Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, has left for China where he will assume the following duties with the National Agricultural Research Bureau, Ministry of Industries, Shaolingwei, Nanking 10, China: (1) To advise on methods of breeding wheat, rice, cotton, sweet and Irish potatoes, and possibly tobacco; (2) to supervise a coordinated program for the whole nation in breeding these crops; (3) to advise on breeding disease-resistant varieties; and (4) to train in methods of plant breeding a selected group of Chinese field workers, most of whom have had graduate training abroad, especially in the United States. Dr. H. K. Wilson will serve as Acting Chief of Division during his absence.

J. O. CULBERTSON, Assistant Agronomist, Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, has been transferred from Salt Lake City, Utah, to the University of Minnesota, St. Paul, Minn. Mr. Culbertson will continue agronomic investigations with sugar beets, taking over those phases of work formerly under the charge of Dr. F. R. Immer.

DR. K. H. KLAGES, formerly of South Dakota State College, has been appointed head of the Department of Agronomy, University of Idaho, succeeding Professor H. W. Hulbert who has resigned to join an Idaho seed firm.

DR. L. E. KIRK, Dominion Agrostologist, Ottawa, Canada, delivered the seventh series of the annual lectures given in recognition of the plant breeding achievements of Frank Azor Spragg, plant breeder at the Michigan Agricultural Experiment Station from 1906 to 1924. The lectures, sponsored by the Department of Farm Crops, Michigan State College, were given March 10 to 13 and covered the following subjects: Organization of Forage Crop Research in Canada; The Improvement of Pasture Grasses and Legumes; Pasture Research at Ottawa; The Breeding of Alfalfa; and Production and Control of Pedigreed Seed in Canada.

DR. CHARLES E. THORNE, Director and Chief of the Soils Department of the Ohio Agricultural Experiment Station from 1887 to 1921 and Director Emeritus since then, died at his home at Wooster on February 29 in his ninetieth year. Dr. Thorne was active up to the last, and since his retirement from the directorship in 1921 he worked almost steadily in summarizing and interpreting the results of the long-time fertility experiments at Wooster and those of the Pennsylvania and Rothamsted Experiment Stations.

DR. A. L. GRIZZARD, formerly assistant agronomist at the Virginia Agricultural Experiment Station in charge of T. V. A. fertilizer investigations in Virginia, has been advanced to associate agronomist in charge of a pasture research project inaugurated under the Bankhead-Jones Act. Mr. E. M. Dunton, Jr., a graduate student in Agronomy and Agricultural Chemistry, has been appointed to fill the vacancy caused by Dr. Grizzard's promotion.

Dr. S. S. OBENSHAIN, formerly assistant agronomist at the Virginia Agricultural Experiment Station in charge of soil survey, has been advanced to associate agronomist and will have charge of the soil teaching and investigational work formerly carried by the late Dr. N. A. Pettinger.

The summer meeting of the corn belt section of the American Society of Agronomy will be held at the University of Illinois, Urbana-Champaign, Illinois, June 23, 24, 25. 1936.

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A DIRECT METHOD OF AGGREGATE ANALYSIS OF SOILS AND A STUDY OF THE PHYSICAL NATURE OF EROSION LOSSES[1]

ROBERT E. YODER[2]

SOIL aggregation is one of the most important dynamic properties of soils to be considered by the investigator dealing with soil tilth, erosion control, and other problems in soil physics. The property of aggregation in soils has received considerable attention by numerous European workers. Tiulin (14)[3] and Sokolovsky (12) have amply reviewed the investigations of the Russian workers who have long realized the practical significance of this soil characteristic. Ehrenberg (4) has presented a comprehensive review of the literature treating this subject. Baver and Rhoades (1) have actively led the work on aggregation of soils in this country for the past 3 years. Baver and his co-workers (2, 7, 9) have utilized a modified Kopecky elutriator for the determination of aggregate size distribution in soils.

CRITICISM OF ELUTRIATION METHOD OF AGGREGATE ANALYSIS

The elutriation method is beset with several inherent characteristics which render its application to aggregation studies questionable. A brief discussion of these characteristics follows.

LIMITATIONS IMPOSED BY STOKES' LAW

Particle density.—Application of Stokes' law (13) to the separation of various sized particles implies that they be of uniform density. This is reasonably true of the completely dispersed soil particles dealt with in mechanical analysis. The elutriation principle was advanced for the separation of such particles. However, soil aggregates are not of uniform density. Likewise, the density of aggregates of many soils is quite far removed from that of their completely dispersed particles (Table 1). The extreme variability of settling velocity of aggregates of uniform size caused by variations in aggregate density

[1]Contribution of the Department of Agricultural Engineering, Alabama Agricultural Experiment Station, Auburn, Ala. Published by permission of the Director. Received for publication January 20, 1936.

[2]Assistant Agricultural Engineer.

[3]Figures in parenthesis refer to "Literature Cited", p. 350.

is sufficient reason for rejecting the elutriation principle as a means of aggregate fractionation.

TABLE 1.—*Mean density of aggregate separates from several soils.*

Soil type	Aggregate separate, mm	Mean density*
Cecil clay	5–2	1.66
Dewey clay loam	5–2	1.25
Westmoreland silt loam	2–1	1.45
Frederick silt loam	2–1	1.25
Hartsells fine sandy loam	2–1	1.75

*These values were obtained from volume-weight measurements determined by filling the voids in a known weight of aggregates, in a volumetric flask under partial vacuum, with mercury.

Particle shape.—Smooth spherical-shaped aggregates are not commonly found in soils. The influence of particle shape on sedimentation velocity has been discussed by Keen (6). It suffices to state that soil aggregates present a variety of shapes; smooth surfaces are not common.

Particle size.—It has been pointed out by Keen (6) that the maximum size limit of soil particles which may be fractionated by methods based on Stokes' law is about 0.50 mm diameter. Many soils contain large quantities of water-stable aggregates greater than 0.5 mm in diameter.

Turbulence.—Stokes' law is valid only when the resistance to particle fall is due entirely to the viscosity of the medium. The elutriator is not free of turbulent flow.

SOIL-WATER RATIO

The quantity of water required to fractionate 10 grams of soil by the elutriation method is usually at least 15 liters. Pure water exerts a weak dispersing action upon the colloidal fraction of soils. Demolon and Henin (5) recommend the addition of $Ca(NO_3)_2$ to the water used for aggregate fractionation. This practice does not seem desirable in the case of soils of low base saturation. While the soil-water ratio is of least importance for highly leached soils, it is desirable (10) to reduce the ratio of soil to water to about 1:100. Ten grams of soil is a very small quantity upon which to determine aggregate distribution. The use of larger quantities of sample for aggregate distribution determinations can be unconditionally recommended.

MECHANISM OF THE SLAKING REACTION

The tendency of soils to break down from clods into smaller aggregates under the influence of moisture changes is one of the most significant dynamic properties of soils in relation to erosion control and tillage practices. Before suggesting a mechanism to account for the slaking reaction, it is appropriate to review briefly several characteristics of the process.

1. The slaking process is complete only when the lump of soil has been allowed to approach closely an air-dry condition. Aggregate analysis of several soils at various moisture contents, as determined by

the method reported in this paper, lead one to believe that the critical moisture condition in question corresponds to the "pendular" moisture stage of drying (6).

2. Lumps of air-dry soil do not slake if they are first slowly wetted by a water supply controlled by capillarity, i.e., by the technic of Sekara (11). Even though such moistened lumps become very soft, they retain their form when immersed in water.

3. Air-dry lumps of soil do not slake appreciably if the air contained in the pore spaces is removed previous to immersion in water; the lumps soften but their form is retained.

4. The slaking reaction does not occur when air-dry soils are immersed in non-polar, non-miscible liquids (xylol, toluol, etc.). Under such conditions the lumps remain firm and rigid even though capillarity causes them to become quickly saturated with the liquid.

5. Small roots, root hairs, and fungus mycelia frequently prevent soil lumps from completely slaking into their water stable aggregates. (This fact probably accounts for an appreciable portion of the decreased erosivity of soils under vegetative protection and other conditions where organic residues are abundant.)

Nature, through the integrated sum of her environmental factors acting through geological time on different parent rock materials, has produced a great variety of soil types, each of which is characterized by some sort of natural structure or aggregate distribution. When a lump of soil is allowed to air-dry, cleavage boundaries caused by differential shrinkage are developed along areas of lowest shear value, i. e., along aggregate boundaries. The aggregates are still coated with a thin film of sorbed water held by the colloidal surfaces. When water is supplied, these films thicken and wedge the aggregates apart; the lump swells and becomes soft. Now, if an air-dry lump is immersed in water, the water penetrates the lump at the highest rate along capillary passageways and cracks of larger dimensions. Since the pore space consists, for the most part, of a contiguous and rather fortuitous system of capillary passageways of varying size and shape, air is trapped in many passageways, particularly those of smaller cross-section dimensions. Next, these small capillaries begin to rob the larger openings of water since a steep gradient of capillary potential is present. This process compresses the entrapped air which finally causes a series of miniature explosions which continue until the lump is shattered into its water stable aggregates.

The aggregates thus formed are termed "water stable" since they are truly stable against the excess of water in which they are immersed. Of course, aggregation like many other physical properties of the soil must be considered as a dynamic property. If such a conception is maintained, the above hypothesis will be helpful to those dealing with soil problems directly dependent upon the dynamics of aggregation.

THE SIEVE METHOD OF AGGREGATE ANALYSIS

The method of aggregate analysis herein reported is based upon the slaking property of soils. A number of the weaknesses of the elutriator method are eliminated.

SAMPLING OF SOILS FOR AGGREGATE ANALYSIS

When one is to determine soil structure, or a soil property depending primarily upon soil structure, care must be taken in order that the structure be not destroyed That sampling method is best which disturbs the natural structure the least. The sampling tube shown in Fig. 1 has been found to be satisfactory. In designing this tube, consideration was given to arch action forces (8) and as a result the driven end of the tube is of such shape that the forces of compression are almost completely vectored away from the core sample. Consequently, compression of the sample is of such low magnitude that it cannot be detected by simple measurements. The tube is thus suited for making volume weight or apparent specific gravity measurements on the sample. Samples should be taken only when the soil content is below that of the lower plastic limit of the soil. Other usual precautions of soil sampling should be observed.

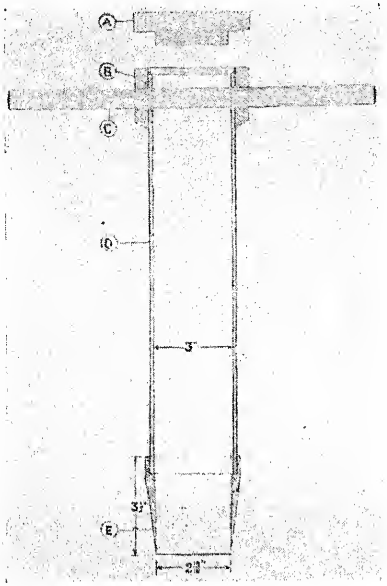

FIG. 1.—Soil sampling tube. A, steel drive cap; B, $\frac{1}{2}$ X 2 inch shoulder strap welded to tube; C, $\frac{3}{4}$ inch removable rod handle; D, $\frac{3}{16}$ X 3 X 14 inch cold drawn seamless steel tube; E, removable, case-hardened steel bit.

PRETREATMENT OF SAMPLES FOR AGGREGATE ANALYSIS

Pretreatment of samples is a factor that should be standardized. Before this is done, careful investigation on the part of several independent workers would be highly desirable. (The following statements are made as a result of considerable work on the aggregation characteristics of soils of the southeastern states. These soils for the most part are acid in reaction and low in organic matter content.) It is suggested that the pretreatment consist only of allowing the sample to approach air dryness closely, immediately before making the analysis if the water stable aggregate distribution is the subject in question. To use samples at "field moisture", as recommended by Baver, simply introduces a variable factor which may lead to erroneous conclusions. Furthermore, it is pointless to determine aggregate analysis on a sample of soil which has been passed through a 2-mm screen as recommended by the above-mentioned worker. Attention is called ot data presented in Table 2. Many soils contain a considerable quantity of water stable aggregates greater than 2 mm in diameter. This pretreatment simply destroys in part that which one is attempting to measure. Shaking in water is also a questionable practice. Such practice is essentially an abrasive treatment, and while it may be admirably suited for studying the mechanical stability of aggregates, it should not be used as a part of an aggregate fractionation process.

TABLE 2.—*Influence of various drying pretreatments on aggregate analysis of Cecil clay.**

Aggregate size class in mm	Percentage of total with drying pretreatment of†			
	None	Oven-dry, 110° C	96% H_2SO_4	Air-dry, 30° C
>2	48.6	66.2	14.3	20.4
2–1	22.4	17.3	24.0	23.1
1–0.5	16.7	10.4	31.0	26.8
0.5 –0.25	5.9	3.1	14.8	14.9
0.25–0.10	3.2	2.0	10.4	10.0
0.10–0.05	1.6	0.7	4.0	3.6
0.05–0.02	0.4	0.1	0.8	0.3
<0.02	1.1	0.2	0.7	0.9

*Cecil clay; mechanical analysis 30.9% sands, 16.2% silt, 52.9% clay.
†Mean values of five replicates.

APPARATUS

The apparatus employed in the proposed method consists of a used "Whirlpool" washing machine which was rebuilt into an aggregate analysis machine. The tub of the machine was converted into a constant-temperature bath. Five cylindrical containers[4], each 6 inches in diameter and 14 inches high, are placed in the water bath. These vessels are supported on a false bottom or grid work located about 2 inches above the agitator fan which is driven by a shaft extending through the true bottom of the tub. Into each cylinder is placed a nest of 5-inch, brass-framed sieves or screens which have openings of 5 mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm (60-mesh), and 0.10 mm (140-mesh).

The sieve junctions are made water tight by placing 1-inch rubber bands, cut from a 4.5 inch innertube, around the nests at appropriate points. Each screen nest is clamped together and against a ¼ x 1 x 5½ inch brass plate placed across the top screen frame by means of 3/16 inch hook-bolts made from bronze welding rod. A ¼ x 4 inch stud mounted vertically at the center of the brass plate serves to connect the nest to the lift mechanism.

The machine is further equipped with an angle-iron framework which supports an elevated deck to which is attached a suitable gear mechanism for raising and lowering the nests of screens through a controlled distance at a controlled rate. A small panel board carries a thermostatic switch, pilot light, and other appropriate switches. Power for operation is obtained from a small motor located beneath the tub.

The entire apparatus, screens excepted, can be collected and assembled at a very meagre cost. The screens, however, cost about $10.00 per nest. The apparatus is shown completely assembled in Fig. 2.

PROCEDURE

Five liters of water are placed in each cylindrical vessel and the containers are then placed in the water bath. The *dry* screens are assembled into nests and then

[4]A six-unit set-up would be desirable.

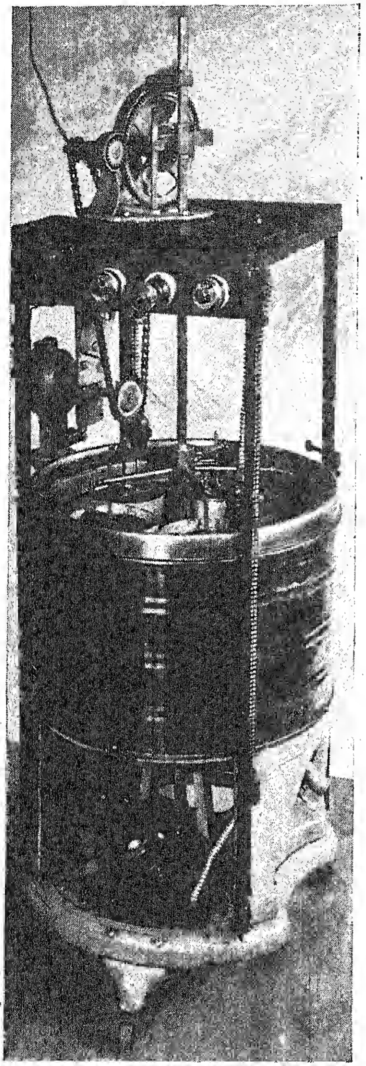

FIG. 2.—Aggregate analysis apparatus completely assembled.

immersed in the water in the cylinders. The nests are then attached to the lift mechanism and minor height adjustments are made to bring the top screen of each nest into such a position that it just remains covered with water when the lift mechanism is at top dead center.

Fifty-gram samples of air-dry soil are added to each nest and the nests are mechanically raised and lowered through a distance of 1¼ inches at a rate of 30 oscillations per minute for a period of 30 minutes. In most instances, the slaking reaction has been completed and the aggregates have become fractionated on the various screens in somewhat less time than the above-mentioned interval. The machine is then stopped and the sieve nests are raised above their respective containers and allowed to drain.

The sieves are then separated, placed on 6-inch petri dishes, put in an 110°C oven, and allowed to dry completely. Then the dried aggregates are removed from the screens and weighed.

The cylinders containing all particles less than 0.10 mm diameter are allowed to remain undisturbed for a time corresponding to the sedimentation interval of 0.05 mm particles and then the suspension is decanted. The 0.10 to 0.05 mm group may be purified by thrice repeated sedimentation and decantation in and from a 500-ml glass cylinder. (The total quantity of particles less than 0.10 mm seldom exceeds 4 or 5% of the total sample except in the case of silty soils of low organic matter content.) If it is desired, the suspended material may be further divided at 0.02 mm—a logical and practical point of division—in the manner mentioned above.

The remaining suspension solids are then flocculated with aluminum sulfate and the clear water is discarded.

The smaller aggregate fractions are easily handled on Buchner funnels if one uses oversized filter paper and a false, metal inner-wall in the funnel to give the filter paper a cup shape. These fractions are also dried at 110°C before weighing.

The above-described apparatus and methods have been used for 2 years in routine laboratory work in connection with the study of certain physical properties of soils in relation to erosion control and tillage practices. The results obtained have been of practical application to these problems.

AGGREGATE DISTRIBUTION IN THE CECIL SERIES

Aggregate studies were made on a number of Alabama soils from the Cecil series on which Davis (3) had collected much information. Soils varying in clay content from 5 to 55% were selected. When aggregate analysis of these soils were made on samples in the *air-dry* condition, a family of closely related aggregate distribution curves was obtained. The results of this study are pictured in Fig. 3.

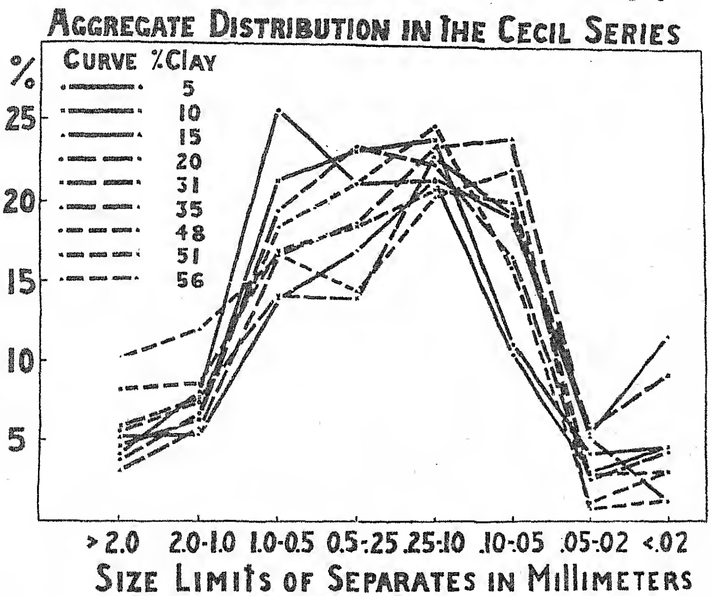

FIG. 3.—Aggregate distribution in Cecil soils of various clay content.

The distribution of water stable aggregates in a large number of samples of soils from important series of the southeastern states has been studied. Several rather contrasting types of aggregate distribution are presented in Fig. 4.

PHYSICAL NATURE OF EROSION LOSSES FROM CECIL CLAY

The physical nature of erosion losses from Cecil clay is but one of several phases of the erosion process which have been studied on the erosion plats of the Agricultural Engineering Department at Auburn, Ala. The general nature of the controlled plat set-up is shown in Fig. 5. Briefly stated, it consists of 10 plats each 15 feet by 50 feet. Two plats are located on each of a 0%, 5%, 10%, 15%, and 20% slope. The soil is a Cecil clay (see Table 3) and is uniform in texture of surface and of subsoil from plat to plat. Suitable equipment and methods are used for (a) measuring rate and amount of natural rains, (b)

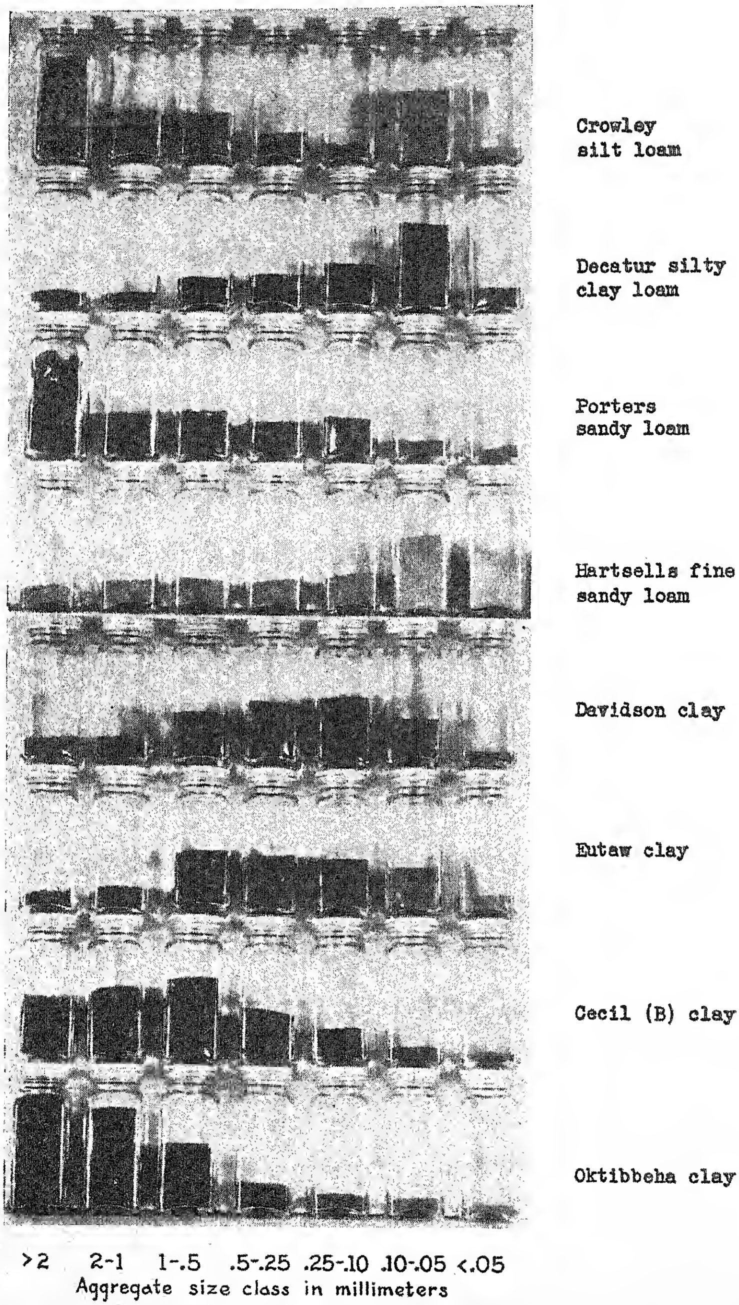

FIG. 4.—Water stable aggregate distribution in soils from different series.

TABLE 3.—*Influence of vetch at different stages of growth on the physical nature of erosion losses from Cecil clay.*

Mechanical analysis of soil (textural separates)		Aggregate size class of eroded sediments,	Aggregate losses in % of total soil losses for slope of									
			0%		5%		10%		15%		20%	
mm	%		Fallow	Vetch	Fallow	Vetch	Fallow	Vetch	Fallow	Vetch	Fallow	Vetch
Losses From 3.92 Inch Natural Rain; Vetch about 50% Ground Coverage												
		>2.0	2.6	1.2	3.4	1.3	14.3	3.4	10.3	4.6	4.4	3.9
2.0 –1.0	0.9	2.0 –1.0	5.0	2.3	9.0	2.2	14.3	4.5	9.5	5.1	9.8	4.5
1.0 –0.5	2.4	1.0 –0.5	9.5	3.8	13.2	6.0	15.5	5.6	10.5	8.1	12.0	8.9
0.5 –0.25	5.4	0.5 –0.25	9.0	4.8	13.9	6.7	11.2	6.4	13.3	9.6	15.0	12.0
0.25–0.10	13.4	0.25–0.10	12.6	8.4	13.5	7.4	13.6	11.8	16.3	17.2	18.6	19.0
0.10–0.05	9.2	0.10–0.05	9.5	9.9	18.3	14.4	13.9	15.4	18.6	16.6	17.9	17.4
<0.05	68.7	<0.05	51.8	69.6	28.7	62.0	17.2	52.9	21.5	38.8	22.3	34.3
0.05–0.005	16.3											
<0.005	52.4	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			167	139	8,247	620	26,354	843	42,915	2,574	54,233	4,527
Run-off, cu. ft. per acre			3,550	3,380	10,755	8,915	10,860	8,850	11,335	9,220	12,875	8,065
Losses From a 2.50 Inch Artificial Rain; Vetch Giving Complete Ground Cover												
		>2.0	3.1	Nil	3.0	Nil	10.4	1.1	6.7	1.5	4.5	1.6
2.0 –1.0	0.9	2.0 –1.0	4.0	Nil	4.3	Nil	11.1	2.7	9.3	3.9	8.4	3.5
1.0 –0.5	2.4	1.0 –0.5	7.5	Nil	18.0	Nil	16.3	5.0	15.8	6.0	14.0	8.5
0.5 –0.25	5.4	0.5 –0.25	6.6	Nil	19.1	Nil	14.3	4.2	16.4	5.6	14.2	12.7
0.25–0.10	13.4	0.25–0.10	19.8	Nil	16.3	Nil	18.0	10.3	19.4	9.7	24.1	11.4
0.10–0.05	9.2	0.10–0.05	14.1	Nil	13.0	Nil	11.2	6.9	10.4	7.7	12.7	8.8
<0.05	68.7	<0.05	44.9	100.0	26.3	100.0	18.7	69.8	22.0	65.6	22.1	63.5
0.05–0.005	16.3											
<0.005	52.4	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			227	8	11,188	6	30,150	26	34,384	48	42,519	521
Run-off, cu. ft. per acre			5,260	3,610	7,600	4,660	7,870	4,610	8,260	4,830	8,770	5,320

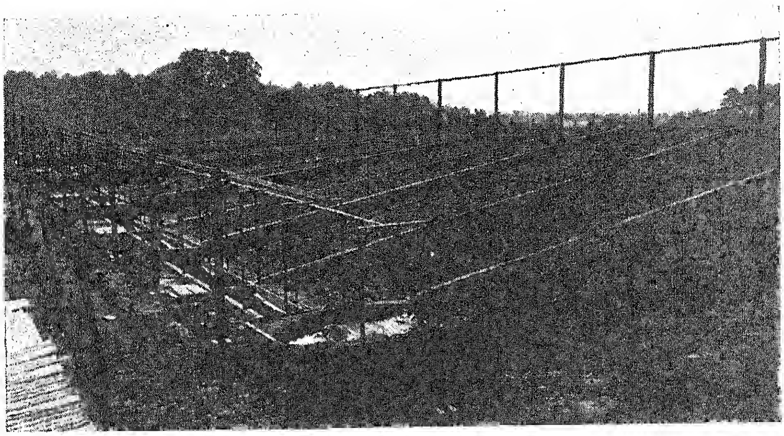

FIG. 5.—View of plat layout for sheet erosion studies, Alabama Agricultural Experiment Station.

supplying uniformly distributed, artificial rainfall at any desired rate and amount, (c) measuring rate and quantity of runoff, and for (d) measuring rate and amount of soil losses.

These plats were primarily designed to study between-terrace or sheet erosion, since the construction and maintenance of proper terraces is generally conceded to be the first step in any sound, long-time program of soil conservation and fertility maintenance in the Southeast.

Aggregate distribution determinations have been made on representative samples of soil material eroded from the above-mentioned plats under a wide variety of soil conditions during the past 2 years. A small portion of the results obtained are presented in order to show the importance of considering soil aggregation in investigational work dealing with erosion control. The wet screening or sieve method of aggregate analysis was used.

The influence of vetch at two different stages of growth on the physical nature of erosion losses may be studied from data presented in Table 3. Data from fallow plats are given for comparison. That aggregates rather than textural separates (sands, silt, and clay) are the particles primarily involved in the erosion process in the case of structural soils, is revealed by a comparison of the mechanical analysis of the soil and of the aggregate analyses of sediments actually eroded from the various plats.

The amount of any given aggregate separate eroded may be obtained by simple calculation from the data given in Table 3. In all cases the cover crop has functioned by filtering out or holding in place large quantities of the coarser separates.

The influence of winter legumes on sheet erosion losses has been studied in considerable detail on the controlled field plats. It has been found that cover crops of this type are effective in reducing sheet erosion losses by (a) minimizing the mechanical dispersion

action of beating rain, (b) decreasing the velocity of run-off and hence decreasing the transporting power of water, (c) decreasing the quantity of run-off, (d) decreasing the turbulence of run-off and hence lessening the abrasive action of sediment-loaded water, and (e) by actually filtering out or holding in place the large water stable aggregates. This type of "vegetative control" practice markedly reduces sheet erosion losses; the soil is held in place. The effect of introducing vetch as a winter legume into continuous cotton culture on the quantity of soil losses over a period of 1 year may be seen from the data given in Table 4.

TABLE 4.—*Erosion losses from continuous cotton with and without winter legumes.**

Period of year	Soil losses in pounds per acre for slope of							
	5%		10%		15%		20%	
	Cotton	Cotton and vetch	Cotton	Cotton and vetch	Cotton	Cotton and vetch	Cotton	Cotton and vetch
Cotton season, June–Oct., inc. . .	18,883	16,344	62,434	62,419	113,800	110,088	138,465	132,493
Vetch season, Nov.–May, inc. .	27,564	3,784	90,218	6,392	135,179	14,767	182,662	19,675
June 1934 to June 1935.	46,447	20,128	152,652	68,813	248,979	124,855	321,127	152168

*Total rainfall for the year was 45.4 inches; cotton season, 21.1 inches; vetch season, 24.3 inches. Vetch used as winter legume planted in drill rows on contour.

Aggregate analyses were also made on sediment samples eroded from the Cecil clay plats on the various slopes when the soil was protected by different widths of strip crop which consisted of vetch at or near a stage of maximum vegetative growth. Artificial rainfall was applied at constant rate and amount when the soil was at low field moisture and again when the surface horizon was saturated with water. Fallow and freshly plowed plat results may be used as comparative check plats in studying these data which are presented in Tables 5 and 6.

The quantity and nature of sediments eroded and the quantity of run-off from two slopes are presented in Table 5. These data show that the strip crop functions by filtering out the coarser aggregates. A summary of the results obtained with the use of various widths of strip crop on the several slopes under controlled conditions is given in Table 6. The width of strip crop required to perform the filtering process is narrow even on a 20% slope.

While these results are impressive, it would be well to bear in mind that a large portion of the reduction in losses through the use of strip crops is apparent only. Soil is sheet-eroded from the non-protected strip and deposited in the filter strip. Neglecting the several unanswered practical farm problems introduced by strip cropping,

TABLE 5.—*Influence of strip cropping on the physical nature of erosion losses from Cecil clay.**

Mechanical analysis of soil (textural separates)		Aggregate size class of eroded sediments,	Slope width of strips†									
			12.5 ft. plowed, 37.5 ft. vetch		25 ft. plowed, 25 ft. vetch		37.5 ft. plowed, 12.5 ft. vetch		50 ft. plowed, no vetch		50 ft. fallow, no vetch	
mm	%		F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd
			Aggregate Losses in % of Total Soil Losses on 5% Slope									
		>2.0	Nil	Nil	Nil	0.2	Nil	0.1	Nil	0.4	2.1	2.6
2.0 –1.0	1.2	2.0 –1.0	Nil	Nil	Nil	0.2	Nil	0.1	Nil	0.8	2.4	5.9
1.0 –0.5	2.9	1.0 –0.5	Nil	Nil	Nil	0.4	Nil	0.1	Nil	1.7	9.2	15.3
0.5 –0.25	6.4	0.5 –0.25	Nil	Nil	Nil	0.3	Nil	0.1	Nil	2.1	12.5	11.1
0.25–0.10	13.0	0.25–0.10	Nil	Nil	Nil	0.8	Nil	0.2	Nil	3.3	23.9	19.1
0.10–0.05	8.5	0.10–0.05	Nil	Nil	Nil	0.4	Nil	0.3	Nil	3.3	16.1	13.8
<0.05	68.0	<0.05	100.0	100.0	100.0	97.7	100.0	99.3	Nil	88.4	34.0	32.2
0.05–0.005	15.9											
<0.005	52.1	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			12	64	38	177	31	293	Nil	1,277	5,027	4,541
Run-off, cu. ft. per acre			960	2,870	1,071	2,839	419	3,358	Nil	3,002	3,195	3,875
			Aggregate Losses in % of Total Soil Losses on 20% Slope									
		>2.0	1.1	1.8	0.3	0.2	0.2	0.1	1.9	7.7	8.6	6.8
2.0 –1.0	0.8	2.0 –1.0	1.6	2.4	0.4	0.4	0.2	0.2	2.0	10.6	13.4	7.8
1.0 –0.5	2.4	1.0 –0.5	4.9	5.3	1.2	1.2	0.6	0.4	5.9	14.2	15.9	12.0
0.5 –0.25	5.5	0.5 –0.25	3.5	5.7	1.4	0.8	1.2	0.8	4.8	12.1	11.7	13.3
0.25–0.10	13.7	0.25–0.10	15.2	9.2	1.8	2.7	2.2	1.9	17.2	17.7	13.0	11.8
0.10–0.05	9.1	0.10–0.05	11.4	6.4	2.9	2.3	3.6	4.9	20.2	13.8	11.1	10.1
<0.05	67.5	<0.05	62.3	69.2	92.0	92.4	90.0	91.7	48.0	23.9	26.3	38.2
0.05–0.005	16.1											
<0.005	52.4	Totals	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total soil losses, lbs. per acre			37	181	156	625	231	1,363	1,794	39,980	25,152	12,377
Run-off, cu. ft. per acre			1,295	3,360	1,129	2,924	885	3,115	450	3,495	3,684	3,902

*Losses from 1.25 inch artificial rainfall in 11 minutes in all cases.
†Slope width of all plats = 50 feet; strip crop below plowed area; plowing done immediately before tests in all cases; F.M. = soil at low field moisture; Sat'd = surface soil saturated, i.e., at maximum water-holding capacity.

TABLE 6.—*Influence of various strip cropping practices on the quantity of sheet erosion losses from Cecil clay.**

Slope %	Soil losses in pounds per acre with slope width of strips†										
	None plowed, 50 ft. vetch‡	12.5 ft. plowed, 37.5 ft. vetch		25 ft. plowed, 25 ft. vetch		37.5 ft. plowed, 12.5 ft. vetch		50 ft. plowed, no vetch		50 ft. fallow, no vetch	
		F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd	F. M.	Sat'd
5	2	12	64	38	177	31	293	Nil	1,277	5,027	4,541
10	33	14	67	28	255	117	377	127	3,743	10,238	6,356
15	33	20	128	29	419	142	632	217	19,402	18,778	9,287
20	107	37	181	156	625	231	1,363	1,794	39,980	25,152	12,377

*Losses from 1.25 inch artificial rainfall in 11 minutes with vetch at full ground coverage in all cases except column 2.
†Slope width of plats = 50 feet; strip crop below plowed area; plowing done immediately before tests in all cases; F.M. = soil at low field moisture; Sat'd = surface soil saturated, i.e., at maximum water-holding capacity.
‡1.08 inch natural rainfall with vetch at approximately 90% ground coverage.

the basic fact remains that sheet erosion is actually not being controlled in the most desirable manner by this type of practice. From the soil loss viewpoint the strip acts similarily to a terrace; that is, a certain portion of the suspended particles are deposited. However, the water of run-off is not conducted away but rather is allowed to continue on down the slope. Upon many soil types on moderate slopes, under certain systems of agriculture at least, "vegetative control" methods should be used to support rather than to replace terracing.

SUMMARY

1. The inherent weaknesses of the elutriation method of aggregate analysis are pointed out and the use of this method of aggregate analysis is questioned.

2. A mechanism is suggested to account for the slaking reaction of soils in the presence of excess water.

3. A direct method, with suitable apparatus for determining the water stable aggregate distribution in soils, is reported.

4. Several soils of the Cecil series with widely varying clay contents were found to have similar distribution of water stable aggregates.

5. Soils from different series were found to be characterized by different distributions of water stable aggregates.

6. The physical nature of the erosion process was studied on carefully controlled field plats of Cecil clay located on several slopes. The losses from this strongly aggregated soil occurred primarily in the form of water stable aggregates.

7. Data are presented which show the effectiveness of winter legumes in controlling sheet erosion losses. The manner in which this type of "vegetative control" functions is reviewed.

8. Results on the use of various widths of strip crop for controlling sheet erosion are presented. The basic weakness of this type of "vegetative control" practice is pointed out.

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TENSIOMETERS FOR MEASURING THE CAPILLARY TENSION OF SOIL WATER[1]

L. A. RICHARDS AND WILLARD GARDNER[2]

NUMEROUS expressions, such as "soil pull", "saugkraft des Bodens", and "force de succion du sol", have been used in the literature to refer to the security with which water is held by soil. With the development of a clearer understanding of the physical relationships involved, this property of soil began to be associated with the condition of the soil moisture, thus leading to the use of such terms as capillary potential, capillary pressure, suction pressure, pressure deficiency, and tension or capillary tension.

Referred to atmospheric pressure as the zero reference, the pressure in water in an unsaturated soil is negative and it will occasionally be desirable to use the term tension or capillary tension as a name for this negative pressure.[3]

The combination of a porous cell and a vacuum gauge for measuring the capillary tension of soil water was early called a capillary potentiometer (2).[4] Heck (4) has used the name soil hygrometer. Both of these terms admit confusion with other better known instruments. Recently, Rogers (6), lacking a more suitable name, has called the combination a soil moisture meter. In the interest of brevity and unambiguity, the name tensiometer is here used. The designation tensiometer has the further advantage of being more descriptive of the function of the instrument.

Accurately speaking, capillary tension is a magnitude which is defined or exists only in the liquid phase of soil water. From a macroscopic viewpoint, though, it may be thought of as a parameter characteristic of the soil mass and as such has particular experimental usefulness because, like temperature and electrical potential, it can be continuously measured and automatically recorded at a given place without disturbing the soil structure, moisture flow, plant growth, or other process which it may be desirable to correlate with soil conditions.

Porous cups intended for use on tensiometers should be carefully tested to see that they will support the desired water tensions without leaking air. The cups used by the writers were made in the laboratory. Sizes have varied from 0.4 cm in diameter and 2.5 cm long to

[1]Contribution from the Soils Subsection, Iowa Agricultural Experiment Station, Journal Paper No. J329, Project No. 487, Ames, Iowa, and the Physics Department, Utah Agricultural Experiment Station, Logan, Utah. Experimental work in connection with the apparatus here described was undertaken by the authors at the Utah Agricultural Experiment Station as part of Utah Station Project 17, in cooperation with the Bureau of Agricultural Engineering, U. S. Dept. of Agriculture. The work was continued at Cornell University where the senior author was Instructor in Physics. Received for publication February 22, 1936.

[2]Research Assistant Professor of Soils, Iowa Agricultural Experiment Station, and Physicist, Utah Agricultural Experiment Station, respectively.

[3]There is ample precedent in physics and engineering for using tension to refer to a state of negative stress. When dealing with soil moisture, the terms tension or capillary tension need never be confused with surface tension or vapor tension because these latter are always used in the form just given.

[4]Figures in parenthesis refer to "Literature Cited", p. 358.

6 cm in diameter and 20 cm long, the choice being determined by the soil space available or the extent of the soil region over which a knowledge of the capillary tension is desired.

The terms "indicating", "recording", and "differential", describe three general types of tensiometers. The following are some typical arrangements which were set up during the summer of 1931 and have been employed in various soil moisture studies since that time.

INDICATING TENSIOMETERS

The form of this type of tensiometer will depend entirely upon the conditions under which it is to be operated. For the small cups, fine-bore mercury manometers are best, but for field work Bourdon gauges with their greater ruggedness have been used to advantage. It is best to have rigid walls for the closed, water-containing system, any rubber connection being as short as possible and made with vacuum tubing. Any gauge will require some transfer of water between cup and soil to change its reading. The smaller this transfer and the larger the area of soil over which it is spread, the greater will be the speed and accuracy with which the gauge indicates changes in the soil water tension.

It is, of course, necessary that good capillary contact be maintained between the porous cup and the soil. By using a flexible rubber connection to the cup or a rigid support for the vacuum indicator, or both, there has been no difficulty satisfying this requirement.

It is important to be able to detect and remove any air which accumulates in a tensiometer. When space permits it is desirable to have the bore and slope of the tensiometer tubes sufficiently large that accumulated air will of itself rise to an upper chamber where it can be detected and removed. A convenient arrangement for this purpose is shown in Fig. 1.

A ½-inch brass pipe cap with its threads removed on a lathe was drilled, threaded, screwed about ¾-inch onto the end of a ¼-inch brass nipple, and soldered in place as shown at Fig. 1, A. The inverted glass tube B, selected to fit in the resulting annular space, was sealed in place with litharge and glycerine cement. A section of ⅛-inch copper tubing, extending to the top of the glass chamber, was brought out the side of the brass nipple through a solder joint at C. Another section of copper tubing was soldered into the brass T, as shown at D.[5] A ⅛-inch copper tube (not shown) connected to the gauge with rubber tubing, passed downward through the hole E to the porous cell in the soil. Weather protection was provided by a cover fitting down over the top of the gauge. By placing tube D in a vessel of water and applying suction to tube C, the system may be completely filled. The rubber tubes are then closed with screw clamps. It is advisable to use only best quality vacuum rubber tubing.

Air tends to accumulate in tensiometers which are in operation.

[5]For the gauge connection described above it was found that occasionally, while the tensiometer was in use, air rising from the porous cell would lodge where tube C enters the ¼-inch pipe nipple. To avoid this it will be desirable in constructing new apparatus to replace the two vertical ¼-inch pipe sections shown in Fig. 1 with ⅜-inch pipe.

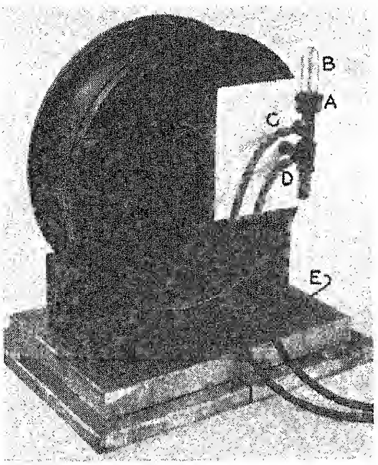

FIG. 1.—Rear view of an industrial vacuum gauge which has been used as a recording tensiometer. See text for a discussion of the arrangement for air detection and removal.

Careful procedure can minimize leaks in connections and through the porous walls of the tensiometer cup, but experience indicates that the water transfer between porous cup and soil which is necessary to change the gauge reading may cause an accumulation of air in the cup because of the effect of pressure on the solubility of gases in liquids. For instance, rain water saturated with air will flow into the porous cup and reduce the gauge reading. The increase in tension which accompanies a subsequent drying of the soil will cause some of this air to come out of solution in the cup. The infusion of air by this process is fairly slow but gauges giving the capillary tension near the soil surface will ordinarily require air removal about once a week.

The presence of air will make a gauge more sluggish in response and the temperature effect on the pressure of the enclosed gas makes it difficult to obtain equilibrium readings.

Bordas and Mathieu (1) have devised a quick-reading tensiometer employing a mercury manometer as the tension indicator. On their instrument the lower part of the mercury manometer is made of rubber tubing so that by raising or lowering the open side of the manometer it is possible to adjust the cup water tension until transfer of water between cup and soil ceases. A drift in the level of the mercury in the closed side of the manometer indicates a flow of water through the cup wall.

The use of tensiometers for studying moisture conditions in the field has been discussed recently by Heck (4) and Rogers (6).

RECORDING TENSIOMETERS

By making use of a recording vacuum gauge it is possible to obtain a continuous record of the capillary tension in soil. Industrial gauges, having a range from 0 to 30 inches of mercury, have been used by the authors for this purpose.[6] The mounting and connections for one of these gauges is shown in Fig. 1 and a typical chart showing, for a period of 1 week, the variation in the capillary tension at a depth of 1 foot in a loam soil is shown in Fig. 2. The sudden drop in the curve occurred at the time of irrigation. The gradual rise indicates the rate at which the capillary tension increased with drying out of the soil.

[6]These gauges, purchased from the Consolidated Ashcraft Hancock Co., Inc., Bridgeport, Conn., were chosen for the purpose because the Bourdon spring with its semi-circular shape can be easily filled and kept full of water.

Five of these instruments have been set up and used in field work and have given highly satisfactory results over a period of years. The results of these investigations will be published elsewhere.

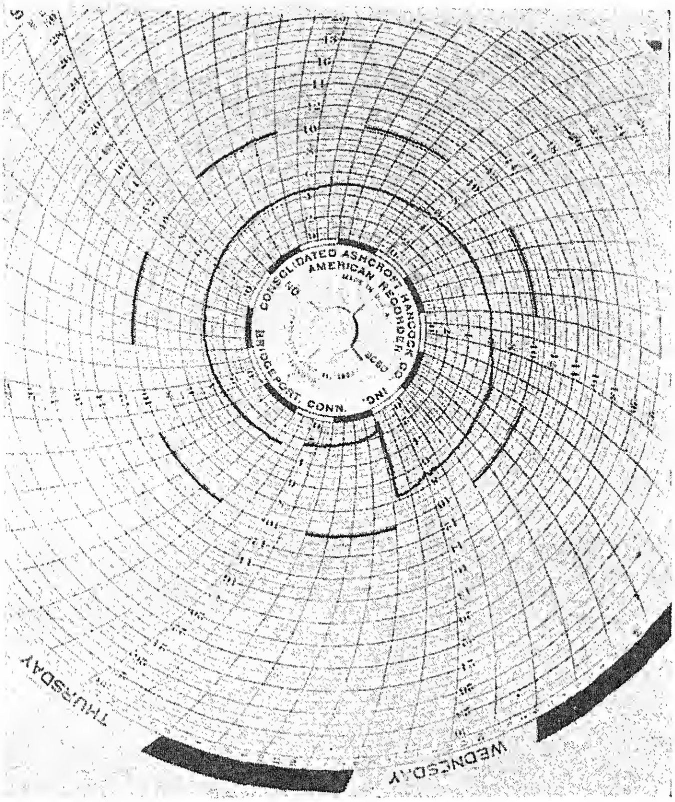

FIG. 2.—Chart from a recording tensiometer showing the variation of the capillary tension at a depth of 1 foot in a loam soil. The sudden drop in tension shows the effect of an irrigation.

DIFFERENTIAL TENSIOMETERS

If two porous cups are filled with water and connected to the two sides of a mercury manometer, the mercury will indicate the difference in the soil water tension at the two cups. Such a system, called a differential tensiometer, provides a convenient means for indicating which way water is moving in a soil. If the two cups are buried in soil and are at the same level, gravity exerts no force to move water from one cup to the other. But, if there is a difference in the capillary tension of the soil surrounding the two cups, the water will flow through the intervening soil in the direction of the cup having the higher tension. Even when the cups are not on the same level, water will move through the soil toward the cup which is connected

FIG. 3.—A differential tensiometer.

to the arm of the manometer containing water at the higher tension. In this case, however, gravity forces enter as a factor determining the flow.

In Fig. 3 is shown a photograph of a differential tensiometer made up so that it can be transferred easily from one place to another in the field and pushed into the soil to indicate the direction of the vertical motion of the soil water. Porous sections, shown at A and B, were mounted by means of DeKhotinsky cement in the side of a $\frac{5}{8}$-inch brass pipe. The porous section A was removed for the photograph. The space behind section A is closed off and connected to the $\frac{5}{16}$-inch copper tube C, which is attached to the left side of the glass manometer D. The space behind B connects directly to the right side of D. The stop cocks, arranged as indicated, make it easy to fill the system with water and to set the reading at zero. With this construction the porous sections may be pushed into the soil to the desired depth without seriously disturbing the soil structure, and an indication of the direction of flow may be obtained in a few minutes. When an equilibrium reading is obtained the average water moving force (w.m.f.) acting in the soil region between two cells is

$$(\text{w.m.f.})_L = \frac{h\,(d_m - d_w) \times 980}{d_w L} \qquad 2$$

Here d_m and h are respectively the density and difference in level of the differential manometer liquid, d_w is the density of the water, L is the distance in centimeters between the two porous cups, and $(\text{w.m.f.})_L$ is the average water moving force in dynes per gram acting in the direction of the line L connecting the two cells. This result is independent of the orientation in space of the line L and the force acts in the direction of the flow.

The differential tensiometer shown in Fig. 3 was inserted in a loam soil with the porous sections at depths of 6 and 14 inches, respectively, below the soil surface and observations were made over a period of 6 weeks. These observations showed that after an irrigation, when the soil had received a thorough soaking, the flow was downward, but this flow decreased

gradually until after several days it was upward for short periods during daytime evaporation. As the top soil dried out still more the periods of upward flow lengthened until, for several days before the next irrigation, the flow was upward both day and night.

Care must be exercised to avoid having the porous sections of a differential tensiometer too far apart. If the capillary tension at some intervening point is greater than or less than the value of the capillary tension at both porous sections, the state of flow cannot be predicted from one set of readings.

In general, the design of a differential tensiometer will depend on the conditions under which it is to be employed. For certain uses the porous sections should be smaller and closer together than those shown in Fig. 3. More sensitivity in the differential manometer may be obtained by using a manometer liquid less dense than mercury. Also, where desired, an open tube manometer may be attached to read the tension of the water at one of the porous sections.

RANGE AND CALIBRATION OF TENSIOMETERS

The range of capillary tension for which tensiometers can be used does not exceed one atmosphere. This is but one-sixteenth of the tension range in going from saturated soil to the wilting point. On a moisture content scale, however, it is found that the major part of the range suitable for plant growth lies in the tension range of 1 atmosphere. For Greenville loam, for instance, 1 atmosphere of tension covers 85% of the moisture content range which will permit plant growth.

In some investigations which involve a consideration of the movement of water through soil or the effect of moisture on life processes in soil, it is likely that capillary tension will be a satisfactory and perhaps the most suitable magnitude for expressing soil moisture condition. Tensiometers are particularly well adapted for use in experiments where different soil treatments on adjacent plats are tested for their effect on soil moisture. In such cases, it will often be unnecessary to know the relation between capillary tension and the moisture content of the soil.

However, when it is desired to go from tensiometer readings to moisture content, experimentally determined calibration curves must be used. A number of examples of these curves and methods for their determination are to be found in the literature (1, 4, 5, 6).

There is a temperature effect which will shift these curves slightly because for a given physical structure and moisture content the capillary tension is proportional to the surface tension of the soil water. Hence, a change in temperature will produce the same percentage change in both the surface tension and capillary tension. The data in Table 1 taken from the International Critical Tables indicate the magnitude of this effect for water. At 20° C it is seen that a 5-degree temperature change causes about a 1% change in the surface tension. The percentage correction to apply to a capillary tension reading which is to be used in connection with a calibration curve made at a different temperature will be the same as the percentage

change in the surface tension between the two temperatures and may be readily calculated.

TABLE 1.—*The surface tension of water in dynes per cm at various temperatures (°C).*

°C	Surface tension, dynes per cm	°C	Surface tension, dynes per cm
0°	75.64	30°	71.18
10°	74.22	40°	69.56
20°	72.75	50°	67.91

The possibility of a hysteresis effect in the relation between capillary tension and moisture percentage must also be considered. For an aggregation of uniform spherical particles the effect may be large (3, 7). This phenomenon has not been sufficiently studied to make possible any generalizations, but for the soils on which reliable data have been published (6) the moisture content width of the hysteresis loop is not greater than 3%.

SUMMARY

The expression "capillary tension" is used as a name for the negative pressure existing in the water in unsaturated soil and porous cell-vacuum gauge instruments used in its measurement are called tensiometers.

Principles underlying the use of indicating, recording, and differential tensiometers are discussed and apparatus used by the authors is described.

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A COMPARISON OF SOIL MOISTURE UNDER CONTINUOUS CORN AND BLUEGRASS SOD[1]

G. R. FREE[2]

THE importance of close-growing vegetation in reducing erosion and run-off is generally recognized. Little information is available, however, concerning the disposition of the water which is prevented from running off by such cover.

The immediate disposition of rainfall may be classed as follows: (a) Part is intercepted by the cover itself and is lost by evaporation without reaching the soil, (b) part is lost as run-off, (c) part enters the soil by a process generally known as infiltration, and (d) part is temporarily stored on the surface and is available for later infiltration or evaporation. The disposition of that part entering the soil may be divided further into the following classifications: Evaporation and transpiration losses, addition to soil moisture in the zone where it is available for plant growth, and addition to subsoil moisture below this zone. The question dealt with by this paper is, Does the water prevented from running off the land by a close cover crop, such as bluegrass, compared with a cultivated row crop, such as corn, remain in the soil?

LITERATURE

Bennett (1)[3] gives data obtained from plats at some of the soil erosion experiment stations which show that close vegetation is effective in reducing erosion and run-off.

Wilson and Welton (6) found that an evaporation index is of considerable value in determining the optimum application of water for bluegrass. A summary of their data is given in Table 1.

TABLE 1.—*Summary of Wilson and Welton data for period of May 1 to Aug. 31, 1934, normal rainfall for period 15.18 inches, evaporation for period as calculated from black atmometer losses 23.94 inches.*

Plat no.	Total water applied, surface inches	Yield of bluegrass, grams per 1,000 sq. ft.
1	21.69	34,615
2	27.69	52,293
3	31.69	46,204
Check*	11.69	22,450

*Check plat received only the rainfall occurring during the period.

It is apparent from these data that bluegrass has a great capacity for utilizing moisture in producing greater yields. If we assume that all moisture applied was lost as evaporation and transpiration, the quantity of water used in the production of 1 gram of crop is between 1,200 and 1,500 grams.

[1]Contribution from Soil Erosion Experiment Station, Clarinda, Iowa. Received for publication February 24, 1936.
[2]Junior Soil Conservationist.
[3]Figures in parenthesis refer to "Literature Cited", p. 363.

Kiesselbach (2) states that the average transpiration requirement of corn in eastern Nebraska is not far from 9 surface inches and that more than two-thirds of the average precipitation of 28 inches for that region is lost in ways other than by transpiration from the corn crop. This figure is a result of potometer experiments which show that about 750 pounds of water are transpired in producing 1 pound of dry shelled corn.

Wallace and Bressman (5) give the following amounts of precipitation as desirable for best corn yields in the central part of the corn belt: May, 3.5 inches; June, 3.5 inches; July, 4.5 inches, and August, 4.5 inches. Optimum mean monthly temperatures together with especially favorable conditions during the critical tasseling period are, ot course, included as a part of the specifications for best yield.

PROCEDURE

At the soil erosion experiment station near Clarinda, Iowa, there is a set of control plats used for determining, among other things, soil and water losses from corn, bluegrass sod, and other crops common to the region. These plats are located on Marshall silt loam which is fully described by Middleton, Slater, and Byers (3). Suffice to state here that the soil is loessial in origin and is quite uniform in texture and permeable in structure to a depth of 3 feet. The water table is far below the ground surface and may be disregarded from the standpoint of moisture available for crop growth.

Near these control plats is another set of plats having identical slope length, exposure, and cropping treatments. These latter plats are used only for determination of soil moisture and yields.

Standard 8-inch rain gages and a Fergusson recording gage are located near these plats and furnish a measure of precipitation falling on them.

The procedure followed in sampling these plats for determination of soil moisture is to take four samples from a 3-foot profile at various times throughout the year. The first sample is taken at a depth of 0 to 6 inches, the second at a depth of 6 to 12 inches, the third at a depth of 12 to 24 inches, and the fourth at a depth of 24 to 36 inches. These samples are then oven-dried at a temperature of 105°C and the moisture expressed as percentage of dry weight. Moisture equivalents of the soil for depths of 0 to 13 inches, 13 to 24 inches, and 24 to 45 inches are 30.1%, 31.8%, and 29.3%, respectively. These values are taken from Middleton, Slater, and Byers (3).

For the study covered in this paper, soil moisture data from only two plats of the series were used, namely, one cropped to continuous corn and one cropped to continuous bluegrass sod. Run-off data for the two crops are taken from the corresponding plats in the control series.

RESULTS

Monthly precipitation data for the years 1932, 1933, 1934, and 1935 are given in Table 2, together with the corresponding normals.

The data from 21 borings for determination of soil moisture are presented in Fig. 1. The first boring of the series was made December 5, 1932, and the last on October 3, 1935. A summary of the soil moisture data is given in Table 3, together with mean differences for the four sampling depths and the results of tests of significance of these differences. Any mean difference is considered not significant if odds of less than 30:1 are obtained.

TABLE 2.—*Precipitation, monthly averages.*

Month	Station average, inches				Calculated station normal, inches*
	1932	1933	1934	1935	
Jan.	1.13	0.32	0.51	0.84	0.58
Feb.	0.72	0.08	0.26	0.54	0.49
Mar.	0.44	3.06	0.11	0.26	0.78
Apr.	2.33	0.91	0.72	0.61	2.65
May.	3.42	3.05	2.55	7.88	4.54
June.	5.26	4.11	2.37	7.06	5.42
July.	2.32	2.27	1.23	1.41	2.95
Aug.	8.10	5.99	2.14	2.79	3.85
Sept.	1.98	4.21	4.82	5.14	3.70
Oct.	1.20	0.87	2.84	3.03	2.64
Nov.	1.14	0.42	3.54	2.50	1.31
Dec.	1.08	1.08	0.13	0.29	0.85
Annual.	29.12	26.37	21.22	32.35	29.76

*Calculated from adjacent weather stations and corrected for station results thus far.

It should be stated at this point that run-off from the continuous corn plat for the entire period totaled 6.57 surface inches as compared to 1.06 surface inches from the bluegrass plat. It is readily apparent from the data that instead of extra soil moisture being available in the bluegrass plat the reverse is true; significantly more moisture is found under continuous corn, except in the one depth 24 to 36 inches where the difference is not significant.

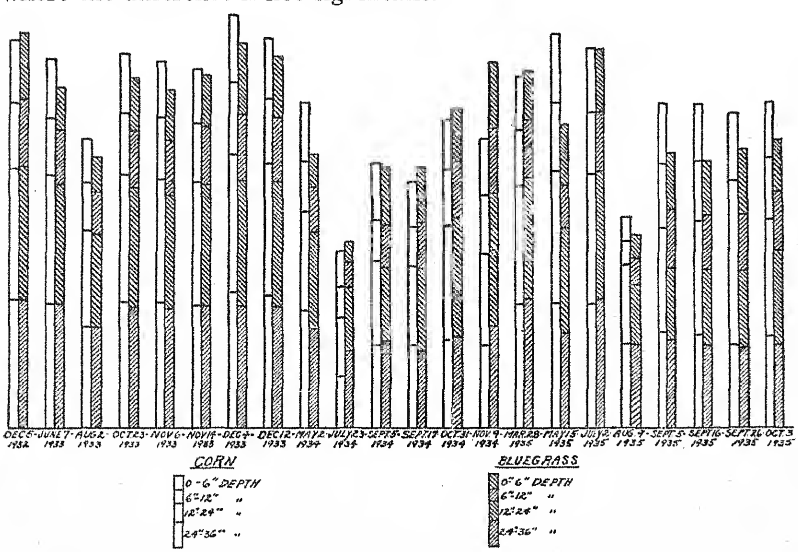

FIG. 1.—A comparison of soil moisture in 3-foot profile under continuous corn and bluegrass.

There remains the possibility that below the 3-foot profile of the bluegrass plat the moisture will be greater, but this is hardly to be expected in view of the significant differences in soil moisture noted above.

TABLE 3.—*Summary of soil moisture data.*

Depth, inches	Average percentage soil moisture		Mean difference	Odds*
	Continuous corn	Bluegrass sod		
0–6	24.38	22.65	1.73	78:1
6–12	24.58	23.33	1.25	30:1
12–24	24.24	22.54	1.70	55:1
24–36	22.83	22.29	0.54	5:1
0–36	23.85	22.61	1.24	78:1

*Determined by Student's method of pairs.

A set of 24 erosion type lysimeters described by Musgrave (4) are located near the plats described above and some data from them will be cited. Percolation from lysimeters of this type containing 3 feet of soil with normal field structure should be indicative of additions to soil moisture below the 3-foot profile in plats where the same cropping practices are followed. At any rate, relative comparisons of percolate from lysimeters with different crops should correspond with relative comparisons of addition to soil moisture below the 3-foot profile in plats with the same crops. From July 1, 1934, to December 31, 1935, the percolation from lysimeters cropped to continuous corn totaled 4.73 surface inches as compared to 1.11 surface inches from corresponding lysimeters planted to bluegrass sod. The absolute difference of 3.62 surface inches in amounts percolated may change as more data are secured, but the relative comparison probably will not.

Since the smaller amount of run-off from bluegrass as compared with corn resulted in neither greater soil moisture content nor greater additions to subsoil moisture below the 3-foot profile, it must be concluded that vapor losses (evaporation and transpiration) great enough to more than offset the extra moisture gained from reduced run-off must have occurred.

It is possible from precipitation, run-off, and soil-moisture data to calculate total moisture losses exclusive of run-off from the 3-foot profile for any period desired. These losses include transpiration, evaporation, and percolation. Table 4 summarizes these losses for the entire period of the study.

TABLE 4.—*Comparison of precipitation and moisture losses.*

	Continuous corn, surface inches	Bluegrass sod, surface inches
Total precipitation	76.49	76.49
Moisture lost as surface run-off	6.57	1.06
Change in moisture content of 3-foot profile (calculated from soil moisture sample data)	—2.14	—3.52
Moisture losses from 3-foot profile other than run-off	72.06	78.95

The percentage run-off of the total precipitation for the period has been 8.6% for continuous corn and 1.4% for bluegrass sod. The sum of transpiration, evaporation, and percolation losses from a 3-foot profile under corn has been 94.2% of total precipitation compared with 103.2% from the profile under the grass cover. The fact that this sum for grass cover is over 100% of total precipitation means, of course, that the net decrease in soil moisture for the period has been greater than the total loss of moisture from run-off.

There is evidence of a cyclical change in soil moisture for both crops. Soil moisture reaches a low point in summer periods when transpiration and evaporation needs are greatest and is replenished during the fall, winter, and spring.

CONCLUSIONS

Soil moisture in a 3-foot profile under continuous corn has been significantly more than that under bluegrass sod despite a difference in run-off of 5.51 surface inches. This difference in available moisture cannot be accounted for by greater additions to subsoil moisture below the 3-foot profile, because under corn, for the period for which percolation data from lysimeters is available, the percolation was greater by 3.62 surface inches.

This condition of less run-off and less soil moisture under bluegrass sod as compared with corn can only be explained by greater evaporation and transpiration losses for the former crop. It is apparent that while the value of a bluegrass sod cover from the standpoint of soil conservation and reduction of run-off is beyond question, the term "moisture conservation" must be used very carefully in order to prevent misunderstanding.

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THE EFFECT OF VARIETY, PLANTING DATE, SPACING, AND SEED TREATMENT ON COTTON YIELDS AND STANDS[1]

G. A. HALE[2]

EXPERIMENTAL data are available on various factors affecting cotton yields and stands where these factors have been studied singly. The work reported here was done with the view of not only determining the highest yielding variety, the best planting date, the optimum spacing of the plants in the row, and the value of treating the seed with Ceresan for the climate and soil (Cecil series) of central Georgia, but also of studying the relationships between these factors affecting yields and stands. A multiple-factor field experiment with cotton or other field crops has many advantages over the common or single-factor experiment where only one variable, such as varieties, is studied.

MATERIALS AND METHODS

Five cotton varieties, three planting dates, three spacings (3 years only), and untreated and treated seed were used for the 5-year period of this experiment. All varieties were planted on each date every year, but only one variety, Stoneville 2, was used in the spacing and seed treatment work. The planting dates, as nearly as soil conditions permitted, were made in late March, late April, and late May, or about one month apart. The spacings tested in 1932, 1933, and 1934 were two plants in hills 1 foot apart with all rows 3.5 feet apart, unthinned plants in hills 1 foot apart, and unthinned plants in hills 3 feet apart. The seed treatment used consisted of dusting the ordinary or undelinted seed with Ceresan (ethyl mercury phosphate).

Eight series of plats for each variety, spacing, and seed treatment were planted on each of the three dates. Eight plats were required to the series except during 1930 and 1931 when only six plats were used because the spacing factor was not included. The series were arranged systematically because of convenience in planting. The plats within each series were randomized or arranged by chance. Seven-row plats with rows 35 feet long and 3.5 feet wide were used. Two or more pickings were made each year and boll samples taken at each picking. The lint yields reported are calculated from lint percentages determined by taking 50-boll samples from each plat at each picking rather than from a single lint percentage determined for one picking and assumed to be correct for all pickings. The number of plants and missing hills were determined on all plats at picking time. All plats were dusted from four to eight times with calcium arsenate to control boll weevils. The results in Table 1 are 5-year averages unless otherwise stated.

VARIETAL EFFECTS

The Half and Half, a medium early maturing variety, was outstanding in lint yield for the average of all plantings and seemed to be especially well adapted for medium and late planting. This variety

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made the poorest relative showing when planted early, although it ranked first in lint yield of all varieties at this date. Observation of this variety in other fields where weevil damage was not reduced by heavy dusting indicates that Half and Half is more susceptible to weevil damage than some of the earlier and quicker fruiting cottons. Stoneville 2, a very early maturing variety, ranked second in average yield for all plantings and was a slightly more consistent producer at all planting dates than Half and Half. Piedmont Cleveland, a medium early maturing variety, ranked third in average yield and had the highest relative yield (using yield at medium date as 100) for the early planting of any variety. This cotton was as high in yielding ability as Half and Half and Stoneville 2 when planted in late March at Experiment, but inferior to them when planted later. Lightning Express, an early maturing variety, ranked fourth in lint yield at each planting date, but made the poorest relative yield when planted late. Deltatype, a medium to late maturing variety, produced the lowest yields but made the best relative yield when planted late, indicating that it was not affected as adversely as other varieties by the hot, dry weather and high weevil infestation which usually prevailed during the fruiting periods of the late planted cotton.

The effects of varieties on cotton stands was difficult to measure in this experiment because it was impossible to calibrate the ordinary cotton planter used so that it would plant exactly the same number of seed of each variety tested, and, too, there were some significant differences in the germination of the seed of the varieties during the first-year plantings when the seed were obtained from the breeders. The Lightning Express variety from both observation and the plant and hill counts presented in Table 1 seemed to be outstanding in seedling and plant vigor when sown at all dates. Deltatype produced the poorest stands.

It is obvious from these different responses of the five varieties tested to the three dates of planting that the time when a cotton varietal test is planted may have a marked influence on the relative rank in yield of the varieties tested. From these results, it may be concluded that varietal tests planted either earlier or later than the optimum or usual cotton planting date for a given locality may be of doubtful value in making varietal recommendation.

PLANTING DATE EFFECTS

Some of the effects of planting date on individual varietal yields have already been discussed. The average yield of all varieties for the late March and late April dates is practically the same with a reduction of 240 pounds of lint cotton per acre as a result of late May planting. Since this late planting was made in small blocks in the same 5-acre field with the earlier dates, it is likely that the yield is somewhat less than would be secured from a late planting in an isolated field where weevil infestation could be controlled more effectively.

The effect on yield of planting date with Stoneville 2 Ceresan-dusted seed as compared with the non-dusted seed was not significant. The influence of planting time on the yield of the three spacings in the

TABLE 1.—*Average results showing the effect of variety, planting date, spacing, and seed treatment on cotton yields and stands at Experiment, Georgia, 1930–34.*

Variety and treatments*	Planted early (late March)			Planted medium (late April)			Planted late (late May)			All planting dates		
	Pounds lint per acre	No. plants per acre	No. hills per acre	Pounds lint per acre	No. plants per acre	No. hills per acre	Pounds lint per acre	No. plants per acre	No. hills per acre	Pounds lint per acre	No. plants per acre	No. hills per acre
Lightning Express	540	18,728	10,777	523	20,939	11,466	282	23,010	11,011	448	20,892	11,085
Half and Half	589	16,144	10,210	626	20,241	11,090	347	22,157	11,096	521	19,514	10,799
Deltatype	463	15,148	9,686	460	18,132	10,755	270	21,874	11,046	398	18,385	10,496
Piedmont Cleveland	580	17,757	10,729	534	18,998	10,964	302	21,933	10,968	472	19,563	10,887
Stoneville 2	570	16,741	10,342	565	19,770	10,887	323	23,103	11,064	486	19,871	10,764
Average all varieties	548	16,904	10,349	542	19,616	11,032	305	22,415	11,037	465	19,645	10,806
Stoneville 2, seed not dusted	573	15,976	9,684	572	21,917	11,246	317	24,608	10,659	487	20,834	10,530
Stoneville 2, not thinned, hills 1 foot apart†	536	37,451	11,328	541	32,323	10,731	269	40,985	10,970	449	36,920	11,010
Stoneville 2, not thinned, hills 3 feet apart†	481	17,557	3,965	505	15,972	3,856	272	18,278	3,397	419	17,269	3,739
Stoneville 2, thinned to 2 plants 1 foot apart†	563	19,129	11,469	541	17,378	10,537	303	17,340	10,872	469	17,949	10,959

*Ceresan dusted and plants spaced 1 foot apart with 2 plants per hill unless otherwise stated.
†3 years only, 1932–34.

row indicates that this factor may be of importance in conducting spacing experiments. The standard or considered optimum spacing of two-plant hills 1 foot apart was relatively better for the early and late dates than the other two spacings. Contrary to expectations, the late cotton gave best yields from the thinnest spacing.

The planting date had considerable influence on the stands as measured by both the number of plants and number of hills per acre. By preparing the seedbed and applying 400 pounds per acre of an 8-4-4 (P-N-K) fertilizer several days before planting and seeding at the rate of 1½ bushels of seed per acre in hills, fairly good stands were obtained every year at all dates. The first planting gave the most irregular stand and the third or latest seeding the best stand.

SPACING EFFECTS

Some of the relationships between spacings and planting dates have been discussed. Although the spacing work is for only 3 years and with only one variety, the results are informative. Two plants per hill and hills 1 foot apart produced 27 more pounds of lint per acre than the next best spacing or the unthinned plat with 1-foot hills when planted early and 31 pounds more when planted late; but when planted at the intermediate date, the two spacings yielded the same or 541 pounds of lint per acre. The unthinned cotton in hills 3 feet apart was inferior to the other spacings at all dates. This spacing has an advantage in cultivation as checked cotton can be kept free of weeds with less hoeing than drilled cotton.

SEED TREATMENT EFFECTS

Dusting cotton seed with Ceresan was not effective in increasing yields. The number of plants was largest at the early and late planting with dusted seed, but dusting seemed to reduce stands at the medium planting date.

CORRELATION BETWEEN YIELD AND STAND

The correlation coefficients in Table 2 show some relationships between lint yields and stands for the three planting dates for each of the 5 years where the varieties were compared. Neither the number of plants per acre nor the number of hills per acre was very highly correlated with the lint yields when the cotton was planted early or

TABLE 2.—*Correlation coefficients between the yield of lint cotton and the number of plants and hills per acre for the three planting dates.**

Planting date	Correlations between lint yield and	
	Number of plants per acre	Number of hills per acre
Early (late March)	.322	.419
Medium (late April)	.586	.789
Late (late May)	.307	.480

*According to tables prepared by Snedecor and Wallace in "Correlation and Machine Calculation", where N = 25, the least significant value for r is .388, while the least highly significant value for r is .496.

late, however, the correlation coefficients for yield and hills per acre are significant. Apparently early planted cotton is able to adjust itself to a wide range of spacing without materially affecting yields. The thick stands of the late planted cotton of this experiment masked any effects of variable stands on yields.

The highly significant coefficients for the medium or optimum planting date for the varieties show that both the number of plants and the number of hills affected yields. From these results it may be concluded that the distribution of the plants as shown by the number of hills is of more importance in obtaining high cotton yields than the total number of plants per acre as shown by plant counts.

SUMMARY AND CONCLUSIONS

Five-year average results of a multiple-factor field experiment with cotton cultural factors including varieties, planting dates, spacings, and seed treatments at the Georgia Agricultural Experiment Station are reported in this paper. This type of experiment was found to have a number of advantages over the common single-variable field experiments where only one factor, such as variety or stand, is varied.

Of the five varieties tested, Half and Half and Stoneville 2 were the highest yielders when all planting dates were averaged. The varieties responded differently to the different dates of planting, indicating that the date of planting of varietal experiments may have a marked effect on the relative yields of the varieties and the value of the results for making cotton varietal recommendations.

The varieties showed some significant differences in their ability to produce satisfactory stands, especially when planted early or during late March at Experiment, Ga.

Of the three planting dates studied, the early (late March) planting and the medium (late April) planting produced the same 5-year average annual yields of lint. The late (late May) cotton yielded only about one-half as much lint as was harvested from the earlier plantings. Stands were poorest on the earlier planted cotton and thickest where the seed was sown in May.

Three-year average results are reported with the Stoneville 2 variety spaced as follows in 3½ foot rows: (1) Not thinned, hills 1 foot apart; (2) not thinned, hills 3 feet apart; and (3) thinned to two plants, hills 1 foot apart.

Two plants 1 foot apart produced the highest yields, except for the medium planting date, when the unthinned cotton in hills 1 foot apart made as much cotton as the thinned cotton spaced 1 foot apart. Contrary to common belief, the unthinned cotton was relatively poorer when late planting was done than for the other dates. The number of hills or the distribution of the plants rather than the total number of plants per acre is most important in spacing experiments. The results show that planting date may affect the ratings of different spacings in cotton spacing experiments.

Treating the Stoneville 2 cotton seed with Ceresan had no significant effects on stands or yields under the conditions of this experiment.

Correlation coefficients are presented to show the relationships between annual yields of lint of the five varieties and the total number of plants and hills per acre.

Where the cotton was planted early, although the stands were somewhat irregular during some seasons, there was no significant correlation between the yield per acre and the total number of plants per acre and only a slightly significant correlation between yield and number of hills per acre. The results for late planted cotton, where stands were good every year, were similar to those for early planting.

The medium planting showed a highly significant, positive correlation between lint yield and both number of plants and hills per acre. The number of hills on the variety plats like those on the spacing plats was more closely and positively correlated with the number of pounds of lint cotton produced than with the number of plants per acre. These results indicate that in studying cotton stands the number of hills may be more important than the number of plants per plat or acre.

HYBRID SELECTIONS OF OATS RESISTANT TO SMUTS AND RUSTS[1]

H. C. MURPHY, T. R. STANTON, and F. A. COFFMAN[2]

THE development of smut- and rust-resistant strains of oats from the cross Victoria × Richland has been reported.[3] To obtain hybrid populations for pathological and genetical studies of certain physiologic forms of crown rust and also, incidentally, to obtain strains equally resistant to smut and stem rust and possibly with better adaptation and greater productiveness, some of the important stem-rust resistant varieties were crossed on Bond by the senior writer in the greenhouse at Ames, Iowa, in the spring of 1932.

MATERIALS

The crosses producing the most promising lines that are not only homozygous for resistance to the smuts and rusts but apparently are agronomically desirable, are as follows:

X M328 Bond (C.I.[4] 2733) x Iogold (C.I. 2329)
X M3217 Anthony (C.I. 2143) x Bond (C. I. 2733)
X M3218 Bond (C.I. 2733) x Iowa No. D69 (C. I. 2463)
X M3214 Green Russian sel. (C.I. 2344) x Bond (C.I. 2733)

Bond was introduced from Australia in 1929. Its history, classification, high resistance to crown rust, and probable agronomic value have been reported by Stanton and Murphy.[5] Bond was nearly immune from all except 2 of 22 physiologic forms of crown rust (*Puccinia coronata avenae* Eriks.) collected in the United States, Canada, and Mexico in 1931–34, inclusive.[6] It was susceptible to rare forms collected in Louisiana and Arkansas only. It is resistant also to collections of loose and covered smut of oats, *Ustilago avenae* (Pers.) Jens. and *U. levis* (Kell. and Sw.) Magn., respectively, obtained from the corn belt, although it has not been uniformly resistant to all collections apparently representing distinct races of the oat smuts from other regions. Bond has an excellent straw, but its complete susceptibility to stem rust (*Puccinia graminis avenae* Eriks. and Henn.) and the pronounced sucker mouth type of hilum make it of doubtful agronomic value. Iogold, Anthony, Iowa No. D69, and Green Russian selection (C.I. 2344) are highly productive, stem-rust resistant varieties, the first two being widely grown and commercially important. All four varieties, however, lack resistance to both smuts and to certain important physiologic forms of crown rust. Iogold has shown no resistance to any of 37 forms of crown rust collected in 1927-35,

[1]Journal Paper No. J-306 of the Iowa Agricultural Experiment Station, Ames, Iowa. Project No. 73. Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station. Received for publication February 12, 1936.

[2]Associate pathologist, senior agronomist, and associate agronomist, respectively.

[3]STANTON, T. R., MURPHY, H. C., COFFMAN, F. A., and HUMPHREY, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24: 165–167. 1934.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations, U. S. Dept. of Agriculture.

[5]STANTON, T. R., and MURPHY, H. C. Oat varieties highly resistant to crown rust and their probable agronomic value. Jour. Amer. Soc. Agron., 25: 674–683. 1933.

[6]MURPHY, H. C. Physiologic specialization in *Puccinia coronata avenae*. U. S. D. A. Tech. Bul. 433. 1935.

inclusive. Anthony and Iowa No. D69 have been resistant to a number of relatively unimportant forms and to the important form 7. Green Russian selection (C. I. 2344) also has been resistant to a number of forms, including some that occasionally are responsible for epiphytotics in the spring-sown oat region. None of these varieties, however, has shown any resistance to the destructive form 1, which is ordinarily responsible for most of the damage caused by crown rust in the United States, especially in the southern states.

METHODS OF HANDLING PROGENIES AND THE RESULTS

The F_1 plants from the four crosses were grown in the cooperative nursery at Ames in the summer of 1932 and were not subjected to any artificial inoculations of smut or rust. In the fall of 1932 some of the seed from these F_1 plants was sown in the greenhouse and the seedling plants were hand-inoculated with physiologic forms 1, 2, and 7 of crown rust and form 2 of stem rust. Plants resistant to all of these forms of both rusts were transplanted into individual pots and grown to maturity. For sowing in the spring of 1933, seed from these resistant F_2 plants was hulled and dusted with a composite collection of loose and covered smut collected from the Ames oat nursery in 1932. Early in the boot stage the F_3 plants were hand-inoculated with the above-mentioned forms of crown and stem rust. The infection resulting from this inoculation was sufficient to allow excellent differentiation for reaction to both rusts. At harvest, several of the F_3 lines were smut-free and apparently homozygous for resistance to both rusts.

Seed from a number of the more promising of these resistant lines was hulled, dusted with smut collected from the smutted F_3 sister lines, and sown in the greenhouse in the fall of 1933. In the seedling stage the plants were inoculated with forms 1 and 7 of crown rust, and at first heading with form 2 of stem rust. A heavy infection of smut was obtained on the susceptible parents and on certain of the families that apparently had escaped infection in the F_3 generation. A few families segregated for reaction to one or both rusts.

In the spring of 1934 remnant seed from all of the resistant F_3 lines grown in 1933 was hulled and dusted with smut collected from the susceptible F_3 sister lines. This seed was sown on April 17 and 18. Non-hulled seed from the resistant F_4 plants grown in the greenhouse was dusted with smut from the same collection and sown on April 27 and 28. Because of the severe drought of 1934, only a few plants grew from the hulled seed sown on April 17 and 18. Excellent germination of the April 27 and 28 sowing was obtained after rains that fell during the last week of June. These rows were irrigated and the early-maturing lines were harvested on September 17, while some of the late-maturing ones were not harvested until October 30. All of the F_5 progenies were harvested as single plants. The reaction to rust of these F_4 and F_5 lines was not obtained because of the complete absence of both rusts. There was a heavy smut infection of the few susceptible lines obtained from the early planting, while there was very little infection of the later planted lines. No smut appeared under field conditions in the lines that were resistant under greenhouse conditions. Previous to sowing in the spring of 1935, the seed

from the individual F_5 plants was carefully selected for absence of the suckermouth hilum present in seed of the Bond parent. Seed from the F_4 and F_5 progenies was not hulled before sowing. It was, however, well blackened with spores of smut collected in the vicinity of Atlantic and Ames, Iowa.

The writers have used Bond as a parent in another cross, *viz.*, Bond (C. I. 2733) × Iowa No. 444 (C. I. 2331), which was not grown continuously at the Agricultural Experiment Station, Ames, Iowa, but from which promising lines have become available. Two hybrids XS1128 and XA1131 of this combination were made by T. R. Stanton and C. Roy Adair, respectively, in the spring of 1933 in the greenhouse at the Arlington Experiment Farm, Rosslyn, Va. The F_1 generation plants were grown at the Aberdeen Substation, Aberdeen, Idaho, in 1933, and the F_2 generation plants from hulled seed inoculated with spores collected at Ames, Iowa, in the greenhouse at the Arlington Experiment Farm in the winter of 1933–34. One-half of the F_2 plants from a common F_1 parent were inoculated with crown rust and the other half with stem rust in the adult stage from cultures received from Ames. At maturity all smutted plants and also all rusted plants showing a type 3 reaction or higher in a 0–4 scale for either rust were immediately discarded. Seed from the resistant plants was bulked and sown in 8-foot nursery rows at the Aberdeen substation in 1934. At harvest only those F_3 plants having desirable plant and grain characters were selected for further testing. Hulled seed from some of the best was dusted with smut from Ames, Iowa, and sown in pots in the Arlington farm greenhouse in the fall of 1934. The seed was inoculated with smut from Ames and the F_4 plants were inoculated with cultures of form 1 of crown rust and form 2 of stem rust, as in the F_2. At maturity only those surviving plants that were smut-free and highly resistant to both rusts were retained. Panicle or head rows from these F_4 plants were sown at Ames in the spring of 1935. The F_5 progenies were subjected to very severe epiphytotics of both rusts. From these progenies only those lines were selected that had satisfactory grain characters, matured normally, and were free from rusts and smuts.

RUST EPIPHYTOTICS, ARTIFICIALLY AND NATURALLY INDUCED, AT AMES

Weather conditions at Ames throughout the season of 1935 were nearly ideal for the development of epiphytotics of both oat rusts. When the oat plants showed first jointing, urediospore suspensions of crown and stem rust were hypodermically injected into susceptible Markton and Carleton plants (mixed, in order to spread the period most favorable for rust inoculation and infection) growing in the alley and border rows. These inoculations were repeated three times during the season and the resulting infection, combined with a heavy natural infection of crown rust and a light infection of stem rust, was so severe as to prevent the production of grain on the Markton and Carleton plants. The rusts spread readily from these susceptible check plants to adjoining rows of hybrid selections. The contrast between the reaction of the resistant and susceptible lines to this

FIG. 1.—Looking across the 5-foot rows and down the alley between series. *Right*, F_6 selections from the cross XM3214 Green Russian selection × Bond, resistant to crown rust, stem rust, and smut. *Left*, F_5 segregates from the cross XM3211 Markton × Bond, susceptible to crown and stem rust, resistant to smut. *Center*, Markton and Carleton (mixed) check growing in alley, susceptible to both rusts, resistant to smut.

very severe infection was striking. Lines resistant to both rusts remained green and erect, ripened normally, and produced high yields. Some of these lines from the cross X M3214 Green Russian selection × Bond are shown in Fig. 1. The leaves of all crown-rust-susceptible plants were killed soon after the panicles were fully exserted. The plants ripened prematurely and produced a low yield of very light grain. All lines susceptible to stem rust lodged early, ripened prematurely, and yielded a very small amount of light grain. Owing to the severe rust infection, the plants were badly lodged before ripening, most of them producing no grain and many of them never heading. The mortality of progenies due to one or the other rust for the nursery as a whole, was exceedingly high. Infection of smut also was abundant on the susceptible lines. All lines previously found homozygous for resistance to the rusts and smuts were outstanding for their resistance in 1935.

CONCLUSIONS

Since the resistant selections considered in the foregoing were subjected in both greenhouse and field to epiphytotics of rust and smut much more severe than those ordinarily occurring under field conditions, it is believed that they will continue to be resistant to natural epiphytotics of these diseases unless some major change occurs in the physiologic-form flora of the corn belt region. These selections appear to be very promising from the standpoint of yield and adaptation, although definite tests of these qualities have not been made.

VARIETAL RESISTANCE OF SMALL GRAINS TO SPRING FROST INJURY[1]

J. B. HARRINGTON[2]

NATURE imposes many limiting factors on crop production and one of these is frost injury to grain crops. On the western plains of Canada and the adjacent areas of the United States, the growing season for spring-sown crops is short, necessitating early sowing, and night temperatures of several degrees below freezing may occur after the grain seedlings have emerged and attained a height of 5 or 6 inches. The plants may be severely damaged with most of the exposed leaf tissues killed. New growth soon replaces the ruined parts, and to the superficial observer the effects of the frost are erased and become a thing of the past. In fact, spring frosts are generally assumed to do little permanent damage to the small grains excepting insofar as the temporary set-back might delay maturity slightly.

It seems more probable, however, that a crop which is badly frosted in the seedling stage suffers permanent injury. In careful work at Fargo, N. D., Waldron (10, 11)[3] calculated that a frost of 6°F reduced the eventual yield of Hope, one of the wheat varieties in his experiment, by 38%. In another test, where the frost was less severe, the loss was much less, but Hope was more injured than any other variety in the test and there appeared to be definite differences in resistance to frost injury with respect to other varieties in the test. Waldron's work indicated that it is a distinct advantage to have varieties with as high a degree as possible of seedling resistance to frost damage.

An excellent opportunity to obtain comparative frost resistance on cereal varieties and hybrids under field conditions presented itself on June 4, 1935, at Saskatoon, Saskatchewan, when a fairly uniformly distributed frost occurred. At this time nearly all of the cereals were in the two-leaf seedling stage and a carefully planned experiment where freezing temperatures could be administered under full control and on an *immense* scale could hardly have produced more satisfactorily differential results.

Before presenting and examining the Saskatoon data, it is of interest to examine some of the recent literature on cold resistance to gain an idea of the amount of reliance to be placed on comparative seedling frost reactions. Martin (5) tested the cold resistance of 12 Pacific Coast spring wheats and found essential agreement between results obtained at the seedling stage and boot stage under both artificial and field conditions. Peltier and Kiesselbach (6), in a study of cold resistance in spring-sown cereals, showed that seedlings in the two and three-leaf stage of development were materially less resistant than seedlings at earlier or later stages of development. Suneson and Peltier (8) reported similarly that "seedlings emerged from 7 to 12 days prior to controlled hardening and freezing,

[1]Contribution from the University of Saskatchewan, Saskatoon, Sask. Received for publication February 28, 1936.

[2]Professor of Field Husbandry. The author is indebted to Messrs. H. Horner, J. Whitehouse, and J. S. Buchanan who took the frost injury notes and made the variance calculations, and to Dr. T. A. Kiesselbach who read the manuscript.

[3]Figures in parenthesis refer to "Literature Cited", p. 387.

and probably on the verge of endosperm exhaustion, were least cold tolerant". Klages (3) earlier had reached the same conclusion in work with nonhardened plants. On the other hand, Tumanov and Borodin (9) concluded from work with winter crops that with artificial freezing methods the frost resistance of seedlings depended largely upon the temperature at which germination took place.

PROCEDURE

The frost of June 4, 1935, injured cereal crops over most of the Saskatoon district. The exact temperatures in the various breeding nurseries during the period of the frost are not known, but the continuous temperature record of the University of Saskatchewan meteorological station situated less than a mile from the cereal nurseries showed the following figures: On June 4 at 1 a.m., 36° F; at 2 a.m., 30°; at 3 a.m., 29°; at 4 a.m., 30°; and at 5 a.m., 36°. The thermograph yielding these records was at an elevation of several feet above the level of the nurseries. Furthermore, the elevation of the different nurseries varied by as much as 10 feet and air movement interferences such as tree belts were closer to some nurseries than to others. Therefore, the actual temperatures in the nurseries probably varied somewhat from those shown by the thermograph.

Most of the cereal variety plat tests were located within an area roughly 800 feet by 800 feet in size. Throughout this area the frost damaged some wheats badly and some barleys very badly. Within the area occupied by any one experiment the frost was fairly uniform judging by the damage in distributed plats of standard varieties.

While the nurseries were not all sown at the same time, the emergence throughout occurred within a period of 6 days, and at the time of the frost the cereal seedlings were nearly all in the two-leaf stage with the third leaf commencing to appear in some cases. The flax was in the two-leaf stage for the most part. Most of the data on frost damage were taken on the second and third day after the frost. Each set of data was analysed biometrically for correlation between date of emergence and frost injury, but no relationship was found.

The frost injury was recorded on an individual plant basis, using a scale from 10 to 0 as follows:

Resistance index	Amount of injury
10	None
9	One leaf slightly
8	One leaf moderately
7	One leaf severely
6	Two leaves moderately or one leaf severely and one slightly
5	One leaf severely and one moderately
4	Two leaves severely
3	Two leaves severely and culm slightly
2	Two leaves severely and culm moderately
1	Two leaves and culm severely
0	All above ground parts killed

In a series of 21 1/40-acre plats (132 feet long and 8 feet wide) of cereal and flax varieties, frost data were obtained from the seedlings in 15 randomized 1-foot sections of row in each variety. A total of 10,500 plants was examined. Somewhat similarly, individual plant notes were taken on more than 1,000 seedlings in a series of 1/1000-acre plats.

Frost notes were also taken on five triple rod-row plat tests as follows: The test of new wheats resistant to stem rust, the test of durum and common wheats, the standard barley variety test, the smooth-awn barley test, and the standard oat test. In all of these tests, while the injury to individual plants was the basic consideration, a single estimate of damage was made for each plat.

As resistance and susceptibility to frost injury are related closely in genetic origin, a complete list of the varieties for which data are presented in this paper is given in Table 1, together with the source and origin of each.

In summarizing and analyzing the data, the frost resistance indices were treated as class values differing by equal increments and subject to the same statistical treatment as any other data which assume the shape of the normal

TABLE 1.—*Source and origin of varieties studied.*

Variety	Univ. of Sask. Accession No.	Canadian Accession No.	Source*	Origin
			Wheat	
C. I. 1095	1750	1866	N. Dak. E. S.	Hope x Ceres
C. I. 1121	1751	1867	U. S. D. A.	Reliance x Hope
Canus	1725	1260	Univ. Alta.	Kanred x Marquis
Ceres	1212	1263	N. Dak. E. S.	Kota x Marquis
E. Triumph	603	1291	S. Wheeler	Bobs natural cross
Garnet	791	1316	C. E. F. Ot.	Preston x Riga M
Golden Ball	1887	1324	U. S. D. A.	South African durum
(H44 - DC) x Ma	1701	1861	Univ. Sask.	(H-44-24 x Double Cross) x Marquis
(H44 - DC) x Ma	1702	1862	Univ. Sask.	(H-44-24 x Double Cross) x Marquis
(H44 - DC) x Ma	1703	1857	Univ. Sask.	(H-44-24 x Double Cross) x Marquis
H44 x Ma	1743	1876	D. R. R. L.	H-44-24 x Reward
H44 x Rew	1735	1856	D. R. R. L.	H-44-24 x Reward
H44 x Rew	1738	1875	D. R. R. L.	H-44-24 x Reward
H44 x Rew	1739	1873	D. R. R. L.	H-44-24 x Reward
H44 x Rew	1740	1872	D. R. R. L.	H-44-24 x Reward
H44 x Rew	1741	1874	D. R. R. L.	H-44-24 x Reward
Hope x Ma	1748	1865	D. E. S. Br.	Hope x Reward
Hope x Rew	1736	1853	D. E. S. Br.	Hope x Reward
Hope x Rew	1737	1864	D. E. S. Br.	Hope x Reward
Hope x Rew.	1744	1878	D. R. R. L.	Hope x Reward
Hope x Rew	1745	1879	D. R. R. L.	Hope x Reward
Hope x Rew	1746	1863	D. E. S. Br.	Hope x Reward
Huron	1252	1344	C. E. F. Ot.	White Fife x Ladoga
Ko. x Ma	1768	——	N. Dak. E. S.	Kota x Marquis
Marquis	7	1397	C. E. F. Ot.	Hard Red Calcutta x Marquis
Marquis	70	1404	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis	100	1404	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis	146	1868	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis	151	1869	Univ. Sask.	Hard Red Calcutta x Marquis
Marquis	1719	1831	C. E. F. Ot.	Hard Red Calcutta x Marquis
Mindum	64	1418	Minn. E. S.	Durum admixture in Hedgerow
Pelissier	41	1461	U. S. D. A.	Mediterranean durum
Pelissier	109	1859	Univ. Sask.	Mediterranean durum
Pelissier	1135	1860	Univ. Sask.	Mediterranean durum
Pnt. x Ma	1742	1877	D. R. R. L.	Pentad x Marquis
Reliance	1851	1498	U. S. D. A.	Kanred x Marquis
Reward	1003	1509	C. E. F. Ot.	Marquis x Prelude
Thatcher	1720	1820	Minn. E. S.	(Kanred x Marquis) x (Marquis x Iumillo)

TABLE 1.—*Continued.*

Variety	Univ. of Sask. Accession No.	Canadian Accession No.	Source*	Origin
			Barley	
Club Mariout	2073	729	U. S. D. A.	Introduced from North Africa
Colsess......	1636	772	Colo. E. S.	Success x Coast
Comfort.....	1698	1107	Minn. E. S.	(Lion x Manchuria) x Manchuria
Glabron.....	1699	1093	Minn. E. S.	(Lion x Manchuria) x Luth
Hannchen....	229	1109	Svalof	
Mens. x Lion.	1769	1105	C. E. F. Ot.	Mensury Ott. 60 x Lion
Newal.......	1726	1089	Univ. Alta.	Manchuria-Lion x O. A. C. 21
Nobarb......	1730	1022	O. A. C.	O. A. C. 21 x Lion
O. A. C. 21...	228	1086	O. A. C.	Selected from Manchuria
Pannier......	1770	1042	U. S. D. A.	Introduced from Tibet
Peatland.....	1721	1112	Minn. E. S.	Selected from Swiss variety
Regal.......	1865	742	Univ. Sask.	(Lion x Manchuria) x Manchuria
Sanalta......	1731	1088	Univ. Alta.	Smooth Awn x Duckbill
Sansbarb 2...	1722	1074	D. E. F. S. C.	Albert x Lion (N. C.)
Sansbarb 3...	2062	746	D. E. F. S. C.	Junior x Lion (N. C.)
Sol..........	1667	782	Univ. Sask.	Selected from Sixty Day
Trebi........	101	1108	U. S. D. A.	Introduced from North Africa
V. H. 9......	1752	——	Univ. Sask.	Velvet x Hannchen
V. H. 13.....	1753	——	Univ. Sask.	Velvet x Hannchen
V. H. 19.....	1754	——	Univ. Sask.	Velvet x Hannchen
V. H. 70.....	1755	——	Univ. Sask.	Velvet x Hannchen
V. H. 105....	1756	——	Univ. Sask.	Velvet x Hannchen
V. H. 149....	1757	——	Univ. Sask.	Velvet x Hannchen
V. H. 151....	1758	——	Univ. Sask.	Velvet x Hannchen
V. H. 153....	1759	——	Univ. Sask.	Velvet x Hannchen
V. H. 264....	1760	——	Univ. Sask.	Velvet x Hannchen
V. H. 266....	1761	——	Univ. Sask.	Velvet x Hannchen
Velvet.......	1239	1102	Minn. E. S.	(Lion x Manchuria) x Luth
Vel. x Char..	1734	1110	D. E. F. Br.	Velvet x Charlottetown 80
Vel. x Mens..	1732	1106	D. E. F. Br.	Velvet x Mensury Ott. 60
Wis. Ped. 38..	2069	1101	Wis. E. S.	Lion x Manchuria
			Oats	
Anthony.....	2001	216	Minn. E. S.	Victory x White Russian
Banner......	144	11	C. E. F. Ot.	Introduced from Europe
D. C. Sel.....	1762	——	S. Dak. E. S.	
Gopher......	1284	14	Minn. E. S.	Selected from Sixty Day
Hyb. 117.....	1763	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 121.....	1764	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 123.....	1765	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 132.....	1766	——	Ohio E. S.	Red Rust Proof x Hulless
Hyb. 137.....	1767	——	Ohio E. S.	Red Rust Proof x Hulless
Rusota......	1724	327	N. D. E. S.	Selected from Green Russian
S-200........	1733	646	D. E. F. Br.	
Victory......	145	426	C. E. F. Ot.	Selected from Probsteier
			Flax	
Bison........	2041	2100	N. D. E. S.	Selected from common seed flax
Crown.......	272	2109	N. D. E. S.	Selected from common seed flax
W. R. 28.....	1727	——	Univ. Sask.	Selected from Crown

*Abbreviations: Univ. Sask.—University of Saskatchewan, Saskatoon, Sask.; D.E.F.— Dominion Experimental Farm; Br.—Brandon, Manitoba; U.S.D.A.—United States Department of Agriculture; Univ. Alta.—University of Alberta, Edmonton, Alberta; N. Dak. E. S.—North Dakota Agricultural Experiment Station; Fargo, N. Dak.; C. E. F. Ot.—Central Experimental Farm, Ottawa; D. R. R. L.—Dominion Rust Research Laboratory, Winnipeg, Man.; Minn. E.S.—Minnesota Agricultural Experiment Station, St. Paul, Minn., U. S. A.; Ohio E. S.—Ohio Agricultural Experiment Station, Wooster, Ohio; Colo. E. S.—Colorado Agricultural Experiment Station, Fort Collins, Colo.; O. A. C.—Ontario Agricultural College, Guelph, Ontario; D. E. F. S. C.—Dominion Experimental Farm, Swift Current, Sask.; Wis. E. S.—Wisconsin Agricultural Experiment Station, Madison, Wisconsin.

probability curve. The plat arrangements and analyses of data for the comparative rod-row tests were made according to the variance methods outlined by Fisher (1) and elucidated by Snedecor (7). In each test frost data were taken on the first four replicates only.

RESULTS

FORTIETH-ACRE PLATS

The series of 1/40-acre plats contained the leading small grain varieties of western Canada. All of the plats were sown on May 14 and emerged on May 25, 26, and 27. At the time of the frost practically all of the plants were in the two-leaf stage. A study of the data revealed no effects attributable to differences in date of emergence.

This series of plats contained wheat varieties alternated with varieties of oats and barley in an unreplicated sequence. However, as the plats were long and narrow and as the frost results checked closely with those from nurseries where randomized replication was used, it is probable that the results represent fairly accurately the relative frost resistance of the different varieties and crops.

The summarized results are given in Table 2. The last two columns of the table show for each variety its frost resistance rank and the position it actually occupied in the field. A glance down the two columns shows no appreciable relationship between rank and location, consequently the fact that the results are from an unreplicated series need not be considered when studying the data.

Within each of the four crops there appear to be significant differences between varieties. Among the wheats Reliance and Mindum were outstanding and showed almost no frost injury. Thatcher came next in resistance. Marquis, Garnet, Apex, and Pelissier were intermediate, while Reward and Ceres showed the least resistance of all of the varieties.

Among the oat varieties Banner and Victory were the least injured, but the differences among the four varieties were not large.

The barley variety reactions were much more differential. Regal was injured relatively little, whereas Colsess was badly injured. Trebi also was fairly severely injured.

The flax test showed a fairly distinct difference between Crown and Bison, the latter being more severely injured. W. R. 28 reacted somewhat like Crown.

A SERIES OF 1/1000-ACRE PLATS

Further frost data on representative cereal and flax varieties were obtained from the series of 1/1000-acre plats which was situated 1,800 feet from the 1/40-acre plats reported upon in Table 2. The results are summarized in Table 3 and closely resemble those of Table 2, except for the oat varieties where the differences were comparatively small in both nurseries. Reliance wheat, Regal barley, and Crown flax were the least injured varieties and Reward, Ceres, Colsess, and Bison the most injured in their respective crops in both sets of results.

TABLE 2.—*The effect of a spring frost on seedlings of spring-sown cereal crops in a series of fortieth-acre plats.**

Variety	Distribution of samples according to the mean degree of freedom from frost injury of the plants of each sample																			Frost resistance rank	Sowing order by plat no.
	4.8	5.1	5.4	5.7	6.0	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9.0	9.3	9.6	9.9	Mean		
										Wheat											
Reliance	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	3	11	9.8	1	12
Mindum	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	5	7	9.7	2	17
Thatcher	–	–	–	–	–	–	–	–	–	–	–	–	2	1	3	3	1	5	9.3	3	19
Garnet	–	–	–	–	–	–	–	1	–	–	–	1	1	2	5	1	2	2	8.9	4	8
Marquis 100	–	–	–	–	–	–	–	–	–	–	2	3	2	4	–	–	4	–	8.7	5	1
Peliss. 109	–	–	–	–	–	–	–	–	1	1	1	4	–	1	4	1	2	–	8.6	6	14
Apex	–	–	–	–	–	–	–	–	–	2	2	2	1	2	4	2	–	–	8.5	7	4
Ceres	–	–	–	–	–	–	–	–	4	2	1	2	3	1	2	–	–	–	8.0	8	10
Reward	–	–	–	–	–	–	1	–	–	3	4	1	3	3	–	–	–	–	8.0	8	6
										Oats											
Banner	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2	5	1	6	9.5	1	2
Victory	–	–	–	–	–	–	–	–	–	1	–	–	–	1	2	3	5	3	9.2	2	3
Anthony	–	–	–	–	–	–	–	–	1	–	–	1	4	3	2	1	1	2	8.7	3	5
Gopher	–	–	–	–	–	–	–	–	1	1	1	1	3	3	1	4	–	–	8.6	4	7
										Barley											
Regal	–	–	–	–	–	–	–	–	–	–	2	4	1	2	1	2	2	1	8.7	1	11
O. A. C21	–	–	–	–	–	–	1	2	–	–	3	3	1	1	2	–	–	2	8.2	2	9
Hannchen	–	–	–	–	–	–	1	2	–	2	4	–	3	1	1	1	–	–	7.9	3	15
Trebi	–	–	–	–	–	1	2	2	1	4	2	2	1	–	–	–	–	–	7.4	4	16
Colsess	2	1	–	2	1	1	4	1	1	1	1	–	–	–	–	–	–	–	6.3	5	13
										Flax											
		1.1	1.4	1.7	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	Mean		
Crown		–	–	–	–	–	–	1	1	2	1	–	2	1	2	–	5	–	4.5	1	21
W. R. 28		–	–	–	1	–	–	1	1	–	1	3	–	3	3	1	1	–	4.3	2	20
Bison		1	–	1	2	–	–	–	2	4	–	1	2	1	–	1	–	–	3.4	3	18

*In each sample there were from 10 to 30 plants. Frost injury of individual plants was recorded as 0 if killed to ground and up to 10 for no injury in the case of cereals, and 0 to 6 for flax.

TABLE 3.—*The effect of spring frost on varieties of small grains and flax grown in a series of 1/1000-acre plats.*

Variety	Degree of frost resistance	Frost resistance rank
	Wheat	
Reliance	9.2	1
Garnet	8.2	2
Marquis 100	7.0	3
Reward	6.6	4
Ceres	6.4	5
	Oats	
Gopher	9.8	1
Victory	9.4	2
Banner	7.9	3
	Barley	
Regal	9.2	1
Hannchen	8.9	2
O. A. C. 21	8.8	3
Trebi	8.1	4
Colsess	5.4	5
	Flax	
Crown	5.0	1
Premost	3.8	2
Bison	3.2	3

Substantiation of the principal differences in these tests was found in other places. For example, the Colsess on University Seed Farm was killed almost down to the ground while a nearby field of Regal was only moderately injured. Again, the Marquis on University Seed Farm was badly injured, but Reliance was barely touched by the frost.

REPLICATED ROD-ROW PLAT TESTS OF WHEAT VARIETIES

The rod-row plat tests of small grains were situated approximately 800 feet from the fortieth-acre plats and experienced more severe frost damage than the latter. The test of new rust resistant wheats was sown on May 9 and emerged on May 21 and 22. The results from four replicates are given in Table 4. The other test was a six replicate triple rod-row plat test of various common and durum varieties many of which were also in the foregoing test. The test of durum and common wheats was sown on May 10 and emerged on May 22. The summarized results from four replicates are presented in Table 5. The two tests were adjacent, the former being slightly nearer to the fortieth-acre plats.

The variance analysis of the results from the test of rust resistant wheats revealed highly significant differences between varieties as described at the foot of Table 4. The actual data from each of the four replicates are given in the table to show the consistency of the results. Canus, a variety from the cross Kanred winter wheat x Marquis, was only slightly injured and appeared to be significantly

TABLE 4.—*Resistance to spring frost injury in a test of 25 varieties of common wheat.*

Variety or hybrid	Sask. Acces. No.	Index of frost injury					Frost resistance rank
		Repl. 1	Repl. 2	Repl. 3	Repl. 4	Mean and SE*	
Canus	1725	9	7	8	9	8.3 ±.90	1
Thatcher	1720	5	5	7	6	5.6 ±.61	2
Early Triumph	603	6	4	7	5	5.5 ±.60	3
Garnet	791	7	3	4	7	5.3 ±.57	4
Huron	1252	6	4	4	6	5.0 ±.54	5
Hope x Marquis	1748	4	4	4	5	4.3 ±.46	6
H-44-24 x Reward	1739	6	3	3	5	4.3 ±.46	6
H-44-24 x Reward	1743	6	3	4	4	4.3 ±.46	6
Marquis	1719	6	2	4	4	4.0 ±.43	7
Reliance x Hope	1751	4	3	4	5	4.0 ±.43	7
(H-44 x Doub. Cr.) x Marq	1703	4	3	3	5	3.8 ±.41	8
(H-44 x Doub. Cr.) x Marq	1702	5	2	5	3	3.8 ±.41	8
Ceres	1212	6	2	4	3	3.8 ±.41	8
Pentad x Marquis	1742	4	3	4	4	3.8 ±.41	8
(H-44 x Doub. Cr.) x Marq	1701	5	2	3	4	3.5 ±.38	9
H-44-24 x Reward	1741	3	4	3	4	3.5 ±.38	9
Hope x Reward	1745	4	3	3	4	3.5 ±.38	9
Hope x Reward	1737	4	3	3	3	3.3 ±.35	10
Hope x Reward	1736	3	3	4	3	3.3 ±.35	10
Reward	1003	3	2	3	4	3.0 ±.33	11
H-44-24 x Reward	1735	3	3	3	3	3.0 ±.33	11
H-44-24 x Reward	1740	5	2	2	3	3.0 ±.33	11
H-44-24 x Reward	1738	3	3	3	3	3.0 ±.33	11
Hope x Reward	1746	2	2	3	4	2.8 ±.30	12
Hope x Reward	1744	3	1	3	3	2.5 ±.27	13

*The variety variance divided by the error variance gave F = 8.0. The 1% point = 2.07. The standard error of the mean index of injury of a variety [S.E.y] = 10.9%. The odds are more than 20 : 1 that varieties below the solid line were more injured than Thatcher and that varieties below the dotted line were more injured than Marquis.

more frost resistant than any of the other varieties in the test. Thatcher, a new hybrid variety, was next highest in frost resistance and appeared significantly less injured than Marquis or Ceres and very significantly less injured than Reward. Most of the new hybrid varieties were significantly more injured than Thatcher, Early Triumph, and Garnet.

Highly significant varietal differences were found also in the frost results presented in Table 5. Mindum, Canus, and Reliance were high in frost resistance. All varieties below Reliance appeared to be significantly more injured than Mindum, as shown by the star and bar in the first column after the standard errors. Ceres and Marquis were intermediate in frost injury and Reward was one of the most susceptible varieties.

TABLE 5.—*Resistance to spring frost injury in a quadruplicate randomized rod-row plat test of 24 varieties of durum and common wheat.*

Variety or hybrid	Univ. Sask. Acc. No.	Frost injury index and SE*	The odds are more than 20:1 that the variety starred was less injured than any below the lower bar and more injured than any above the upper bar in the same column					Frost resistance rank
Mindum	64	9.3 ±.72	*					1
Canus	1725	9.0 ±.69						2
Reliance	1851	8.5 ±.65			—			3
Golden Ball	1887	7.5 ±.58						4
Pelissier	41	7.5 ±.58		*				4
Thatcher	1720	7.5 ±.58	—			—		4
Pelissier	109	7.0 ±.54						5
Pelissier	1135	6.3 ±.49						6
Hope x Ceres	1750	6.0 ±.46					—	7
Garnet	791	5.8 ±.45		—	*			8
Hope x Reward	1737	5.5 ±.42						9
(H-44-DC) x Ma.	1702	5.3 ±.41						10
Ceres	1212	5.3 ±.41						10
Marquis	7	5.3 ±.41						10
Marquis	100	5.3 ±.41				*		10
(H- 44-DC) x Ma.	1701	5.0 ±.39						11
(H- 44-DC) x Ma.	1703	5.0 ±.39						11
Marquis	70	5.0 ±.39						11
Marquis	146	4.8 ±.37						12
Marquis	151	4.5 ±.35			—		*	13
Marquis	1719	4.3 ±.33						14
Reward	1003	4.3 ±.33						14
H- 44 x Reward	1735	4.3 ±.33				—		14
Kota x Marquis	1768	3.8 ±.29						15

*F value for variety variance divided by error variance = 21.7. The 1% point = 2.07. SE_V = 7.7%.

Eleven varieties were in both tests. The frost resistance rank of these varieties in Table 4 is 1, 2, 4, 7, 8, 8, 8, 9, 10, 11, 11, and in Table 5 it is 2, 4, 8, 10, 11, 10, 10, 11, 9, 14, 14. Except that Sask. 1703 and Sask. 1737 are not in the same relative positions in the two tables, the agreement between the results of the two tests is excellent. It is of interest to note in Table 5 that the four durum varieties ranked high in frost resistance whereas all of the Marquis strains were in the lower half of the list. It is also of interest that Garnet appeared significantly less injured than Reward in both tests.

The results presented in Tables 2, 3, 4, and 5 demonstrate clearly that both the standard wheat varieties and the new hybrid varieties differed very significantly in the amount of injury they sustained as a result of the June frost. The rank of the different varieties with respect to frost injury was surprisingly consistent in the three experiments. Reliance, Canus, and Mindum in each case took first, second, or third place. Reward and some of the new hybrid wheats were

correspondingly at or near the bottom. Marquis strains assumed intermediate positions along with Ceres and Garnet.

REPLICATED ROD-ROW PLAT TESTS OF BARLEY

The test of smooth-awned barley varieties was grown less than 200 feet from the fortieth-acre plats reported on in Table 2. The seeding was done on May 14 and emergence took place on May 23 and 24. The summarized results on frost injury in four of the replicates are given in Table 6. Glabron, Regal, Comfort, and Velvet, all hybrid varieties of similar parentage, proved the most frost resistant. Hannchen, O.A.C. 21, and Trebi, three standard varieties of western Canada, appeared to be significantly more injured than Glabron. Five of the newest smooth-awned barleys were at the bottom of the list being significantly more injured than Hannchen.

TABLE 6.—*Resistance to spring frost injury in a four replicate randomized rod-row plat test of 16 barley varieties.*

Variety	Frost injury index and SE*		Frost resistance rank
Glabron	8.8	±.63	1
Comfort	8.5	±.61	2
Velvet	8.3	±.59	3
Regal	8.3	±.59	3
Hannchen	7.0	±.50	4
O. A. C. 21	6.8	±.48	5
Trebi	6.3	±.45	6
Mens. x Lion	6.0	±.43	7
Wis. Ped. 38	6.0	±.43	7
Vel. x Char	5.8	±.41	8
Sanalta	5.8	±.41	8
Newal	5.5	±.39	9
Vel. x Mens	5.5	±.39	9
S. B. 2	5.3	±.38	10
Nobarb	4.5	±.32	11
S. B. 3	4.3	±.31	12

*F value for variety variance divided by error variance = 9.6. 1% point = 2.7. SE_V = 7.1%. The odds are more than 20 : 1 that varieties below the solid line were more injured than Glabron and that varieties below the dotted line were more injured than Hannchen.

The summarized results from the test of standard barley varieties and new smooth awned hybrids are shown in Table 7. This test was situated about 150 feet from the wheat test reported in Table 5. It was sown on May 15 and emergence occurred on May 24 with a few plats on May 25 and 26. The figures on the standard varieties Regal, Hannchen, Trebi, O. A. C. 21, and Colsess agree closely with the results given in Tables 2, 3, and 6. Four of the Velvet Hannchen lines ranked close to Hannchen and Regal, while five of the others were more frost injured than Regal by odds of more than 21 : 1. However, the least frost resistant of the Velvet Hannchen lines appeared to be significantly more resistant than Colsess, Peatland, Club Mariout, Sol, and Sansbarb 2.

TABLE 7.—*Resistance to spring frost injury in four replicates of a randomized rod-row plat test of 20 barley varieties.*

Variety	Frost injury index and SE*	Frost resistance rank	The odds are more than 20:1 that the variety starred was less injured than any below the lower bar and more injured than any above the upper bar in the same column			
VH 266	9.5 ±.58	1	*			
Regal	9.3 ±.57	2				
VH 9	9.0 ±.55	3				
VH 70	9.0 ±.55	3				
Hannchen	8.5 ±.52	4				
VH 153	8.5 ±.52	4		*		
O. A. C. 21	8.3 ±.51	5				
VH 149	8.3 ±.51	5				
VH 19	7.8 ±.48	6				
VH 264	7.8 ±.48	6				
VH 151	7.8 ±.48	6	—		*	
VH 13	7.3 ±.45	7				
VH 105	7.0 ±.43	8				—
Pannier	6.8 ±.42	9		—	—	
Trebi	6.0 ±.37	10				
Sans Barb 2	5.5 ±.34	11				*
Sol	5.3 ±.32	12				
Peatland	4.8 ±.29	13				—
Colsess	4.0 ±.24	14				
Club Mariout	3.3 ±.20	15				

*F value for variety variance divided by error variance = 16.9. 1% point = 2.5. SE_V = 6.1%.

REPLICATED ROD-ROW PLAT TEST OF OAT VARIETIES

The test of oat varieties was adjacent to the barley test reported in Table 7. The test was sown on May 17 and emerged mostly on May 27 with some plats on May 26 and 28. The frost notes are reported

TABLE 8.—*Resistance to spring frost injury in a four replicate rod-row plat test of 12 oat varieties.*

Variety	Frost injury index and SE*	Frost resistance rank
Victory	9.0 ±.47	1
Gopher	8.8 ±.46	2
Anthony	8.8 ±.46	2
Rusota	8.8 ±.46	2
Banner	8.5 ±.45	3
D. C. Sel	8.5 ±.45	3
Hyb. 123	8.0 ±.42	4
Hyb. 117	8.0 ±.42	4
Hyb. 121	8.0 ±.42	4
Hyb. 132	7.8 ±.41	5
....	....	....
Hyb. 137	7.0 ±.37	6
S.—200	4.8 ±.25	7

*F value for variety variance divided by error variance = 7.6. 1% point = 2.74. SE_V = 5.3%. The odds are more than 40:1 that varieties below the dotted line were more injured than Victory.

in summarized form in Table 8. Among the varieties Victory, Gopher, Anthony, and Rusota were the least injured. Banner and D. C. Selection were next. None of the Ohio hybrids were as resistant as the standard varieties and as a group they were significantly more injured than the four varieties of highest rank. One variety, S. 200, was much more injured than any other variety in the test.

DISCUSSION

ECONOMIC IMPORTANCE OF FROST RESISTANCE

Cool growing conditions are best for wheat, oats, and barley in the early growth stages, but when these cereals are sown in western Canada early enough in the spring to have such conditions there is a fair likelihood that the temperature will sink below 32° once, and perhaps more than once, after the crop is up. Frost damage to seedling wheat has been shown by Waldron (10, 11) to have an adverse effect on the height and grain yield of the crop. It is probable that frost damage to seedling barley and oats likewise has a detrimental effect on yield.[4] In the case of flax it is well known that frost in the seedling stage may damage the crop extensively. It appears that for western Canada and the adjacent plains region of the United States there is a definite need for as high a degree as possible of seedling resistance to frost injury in the varieties in general use.

VARIETAL DIFFERENCES

In the present study highly significant differences in frost injury were found among the wheat, oat, barley, and flax varieties commonly grown in western Canada. Recent literature shows that such differences may be expected. Harlan and Shaw (2) tested a number of barley varieties for frost resistance at high altitudes in Idaho and found large differences in resistance, some varieties from high altitudes in Asia being far more cold resistant than most of the other varieties. McFadden (4) mentioned in 1930 that Hope wheat was more susceptible to frost than most other hard red spring wheats. Martin (5), in his cold resistance study of spring wheats, also found large differences between varieties. Peltier and Kiesselbach (6), using artificial refrigeration in Nebraska, obtained highly significant differences in cold resistance within each of the spring-sown crops of wheat, oats, and barley.

CONSISTENCY OF VARIETAL DIFFERENCES

The data in the present study were secured under natural field conditions from several different experiments situated hundreds of feet apart, yet the results are markedly consistent. This consistency is best seen when the rankings of the standard varieties are brought together from the various tables. In Table 9 the rankings are given for all varieties which appear in two or more of Tables 2 to 8.

This tabulation demonstrates that the amount of seedling frost injury in a given variety in one nursery was a good indication of

[4]Results which confirm this view have been obtained at Saskatoon and are to be published soon.

TABLE 9.—*Consistency of varietal differences.*

Variety	Table number							Average
	2	3	4	5	6	7	8	
Wheat								
Reliance	1	1	—	1	—	—	—	1.0
Garnet	2	2	1	2	—	—	—	1.8
Marquis	3	3	2	4	—	—	—	3.0
Ceres	4	5	3	3	—	—	—	3.8
Reward	4	4	4	5	—	—	—	4.2
Barley								
Regal	1	1	—	—	1	1	—	1.0
Hannchen	3	2	—	—	2	2	—	2.2
O. A. C. 21	2	3	—	—	3	3	—	2.8
Trebi	4	4	—	—	4	4	—	4.0
Colsess	5	5	—	—	—	5	—	5.0
Oats								
Victory	2	2	—	—	—	—	1	1.7
Gopher	3	1	—	—	—	—	2	2.0
Banner	1	3	—	—	—	—	3	2.3
Flax								
Crown	1	1	—	—	—	—	—	1.0
Bison	2	2	—	—	—	—	—	2.0

the amount in the same variety in other nurseries. In oats, Banner and Gopher changed places in Tables 2 and 3, but the differences between the varieties were relatively small.

It is of interest that the results obtained by Peltier and Kiesselbach (6) under artificial refrigeration in Nebraska are in close agreement with the data given here with respect to the varieties that were tested at both Lincoln, Nebr., and Saskatoon, Sask. These varieties are Glabron and Trebi barley and Ceres, Garnet, and Marquis wheat.

GEOGRAPHICAL ANCESTRAL INFLUENCES

Throughout the frost injury data there appears to be a relationship between remote ancestry and susceptibility to frost damage. That is, on the whole, varieties coming from warm regions of the earth or having part of their inheritance from such regions appear to have suffered more frost damage than those coming from cold regions. This is especially noticeable in the case of wheat and warrants a close inspection of ancestral influences.

It is particularly interesting that the wheat varieties possessing inheritance from the hardy winter wheat Kanred showed more frost resistance than the other bread wheats, and that those having emmer and Indian inheritance were as a group distinctly less resistant than the others. The durums also differed, the two warm-country varieties being less frost resistant than Mindum whose ancestors probably came from Russia.

Table 10 shows the frost results groups roughly according to the influence of origin.

TABLE 10.—*Effect of varietal origin on frost resistance.*

Varieties	Information origin	Table number 2	3	4	5	Average for Tables 4 and 5
Mindum	Cold climate durum	9.7	—	—	9.3	—
Reliance, Canus	Half Kanred	9.8	9.2	8.3	8.8	8.6
Thatcher	Quarter Kanred	9.3	—	5.6	7.5	6.7
Peliss., Golden Ball	Warm climate durum	8.6	—	—	6.9	—
(H-44-DC) x Ma. Hybrids	Sixteenth Kanred nearly half Indian	8.5	—	3.8	5.1	4.5
Marquis	Half Indian	8.7	7.0	4.0	4.9	4.2
H-44 x Rew. (C. A. N. 1856) and Hope x Rew. (C. A. N. 1864)	Quarter emmer nearly half Indian	—	—	3.2	4.9	4.1
Reward	Over half Indian	8.0	6.6	3.0	4.3	3.7

Consideration of these results leads to greater emphasis on the influence of origin when planning a breeding program. It is generally recognized that many different character combinations may be obtained by crossing two varieties of diverse origins; and it is well understood that the parental varieties bring with them both favorable and unfavorable characters which may be retained or rejected as desired in the hybrid progeny. But is it as well understood that characters which are not of particular interest for the immediate solution of the problem in hand and which therefore may be ignored or not noticed are nevertheless present in the progeny and may be of considerable importance under a given set of environmental conditions?

SUMMARY

1. On June 4, 1935, a widespread frost occurred at Saskatoon, Sask., and caught most of the cereal breeding and testing nurseries when the seedlings were in the critical two-leaf stage.

2. Highly significant differences in frost injury were found among the wheat, oat, barley and flax varieties commonly grown in western Canada as well as in the new hybrid varieties. Some varieties were badly injured while others showed high degrees of frost resistance.

3. The results in different nurseries, even where they were a thousand feet apart, were very consistent.

4. Frost susceptibility was particularly noticeable in varieties having a large amount of warm-climate ancestry, whereas varieties having mostly cold-climate ancestors were frost resisting.

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SELECTION OF OPEN-POLLINATED TIMOTHY[1]

MORGAN W. EVANS[2]

COOPERATIVE timothy breeding investigations have been conducted at the Timothy Breeding Station, at North Ridgeville, Ohio, for a number of years. Although the primary purpose of these investigations has been the development of new varieties of timothy (*Phleum pratense* L.), incidental studies have been made of the variations which occur and of the extent to which these variations have been transmitted from one generation to another when selected plants have been propagated by seeds produced under natural conditions with no provision for self-pollination. Timothy is largely cross-pollinated under natural conditions, although on some plants a fair set of seed may be obtained by self-pollination (3, 7).[3]

The fact that numerous variations occur has been observed for many years (4, 5, 6). The plants in any field of common timothy vary as to length of stem, earliness or lateness, length of time during which the leaves remain green, and in other ways.

MATERIALS AND METHODS

Plants of timothy selected from meadows, roadsides, and elsewhere comprised original material. These plants were selected for various characteristics, as size or vigor of the plant, length of stems, earliness or lateness, freedom from rust, and tendency for the leaves to remain green as the seeds approached maturity.

The selected plants were grown in a nursery with no attempt to prevent cross-pollination. Seed from selected plants was sown in a bed during the autumn and from 16 to 25 progeny plants transplanted either in late summer or early autumn of the following year.

COMPARATIVE UNIFORMITY OF PLANTS PROPAGATED VEGETATIVELY AND GROWN FROM SEED

Fig. 1 after Evans (2) shows the greater uniformity of the plants grown from seed produced by the original selected plant of Huron timothy (F. C. 3937)[4] in comparison with plants from seed of ordinary unselected timothy.

In check plats of ordinary timothy grown in different series during the years 1929 to 1933, the average of the maximum percentage of plants in full bloom was 72.3. The time during which the plants were in bloom in any one plat was usually approximately 3 weeks, and the maximum percentage of plants in full bloom was not very high. In contrast to this, plants propagated vegetatively from a single plant were very uniform. In 90% of the plats of vegetatively propagated plants, all of the plants in each plat were in full bloom on the same date.

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[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating with the Department of Agronomy of the Ohio Agricultural Experiment Station, Wooster, Ohio. Received for publication March 4, 1936.

[2]Associate Agronomist, U. S. Dept. of Agriculture.

[3]Reference by number is to "Literature Cited", p 393.

[4]Accession number of the Division of Forage Crops and Diseases.

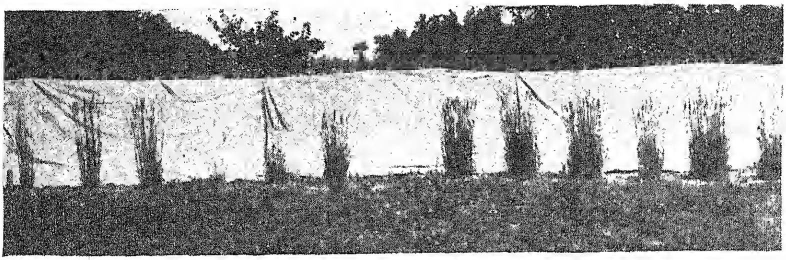

FIG. 1.—*Left*, six plants of ordinary commercial timothy; *right*, six plants grown from seed produced by the original plant of Huron timothy.

Although never so uniform as plants propagated vegetatively, occasionally all, and more frequently 80 to 90%, of the plants in a plat grown from seed of selected strains were in bloom at one time. This is illustrated in Fig. 2 showing the relative dates of blooming in 1933 of ordinary timothy and of an early variety propagated vegetatively and from seed. The plants from seed bloomed but 2 days later than those propagated vegetatively, which were 9 days earlier than ordinary timothy. Although a slight retrogression occurred, the earliness characteristic of the original plant persisted in the plants grown from its seed to a very large degree (2).

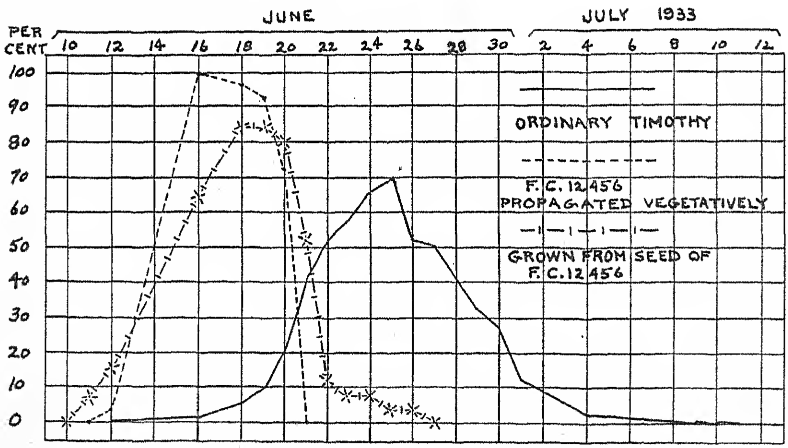

FIG. 2.—Percentage of plants in full bloom of ordinary timothy; of plants propagated vegetatively from the original plant of an early maturing selection; and of plants grown from seed produced by the original plant.

SELECTION FOR LENGTH OF STEMS

Records were taken in 1933 of the length of stem of each plant in a series of 64 plats, 32 of which had been propagated vegetatively from selected individual plants and 32 grown from seed produced by the same original plants. In obtaining the length of stem, the longest stem of each plant was measured from the surface of the soil to the tip of the head.

In the same series were four check plats of ordinary timothy in which the length of stem of all plants averaged 40.2 inches. In only two selections were the average lengths less than those of the checks, and in these the differences were hardly significant. In the five selections having the longest stems the average length of stem of the vegetatively propagated plants was 52.13 inches. The average length of the stem of the plants grown from seeds of these long-stemmed selections was 47.23 inches, or 4.9 inches less than that of the plants propagated vegetatively from the original plants, but 7.0 inches more than that of plants of ordinary timothy. Thus, the plants grown from seed from the five selections having exceptionally long stems, also had long stems. Despite conditions favorable for cross-pollination, the characteristic of long stems is evident to a very large degree in the plants grown from seed for one generation.

SELECTION FOR EARLINESS AND LATENESS

Five pairs were selected in 1917, each pair representing an early and a late selection from a plat grown from seed from a single original plant. Seed harvested from each selected plant was sown in a bed and seedlings were later transplanted to a row plat. In 1922, one of the earliest plants from each early selection and one of the latest plants from each late selection were again selected. Since 1922, selections have been made twice in a similar manner from each early and from each late strain, making a total of four successive generations of selections for earliness and for lateness. The original plants of all generations were retained and seed was again harvested from each. Seedlings of each selection were transplanted to a row plat. In the same series of plats, plants propagated vegetatively and also plants grown from the seed of the original plants from which the first selections were made in 1917 were also grown. In 1929, records were obtained of the dates when the plants in all of these plats were in full bloom.

A timothy head is referred to as being in full bloom when florets are in bloom on two-thirds or more of its length, a plant when 25% or more of the heads are in full bloom and 25% or more additional heads have some florets in bloom and a plat when 50% or more of the heads are in full bloom (1).

A gradual increase in earliness had occurred from one generation to another in the early selections and a corresponding increase in lateness in the late selections. In the third generation, the first for which pairs of selections which had been selected for earliness and lateness were represented, an average difference of 5 days occurred between the early and the late selection, in the fourth generation 9 days, in the fifth generation 13 days, and in the sixth generation a difference of 15 days between the dates maximum percentages of plants were in bloom in the early and late selections. The trends in earliness and lateness continued throughout the course of the experiment, though the increase in spread was somewhat less in the sixth than in the three preceding generations. This is shown graphically in Fig. 3.

Fig. 4 shows the difference in time of blooming of an early and of a late selection both of which were derived four generations earlier from the same original plant.

Within a very few generations both early and late strains have been developed. Progress was more rapid in the earlier generations of selection owing to greater heterozygosity.

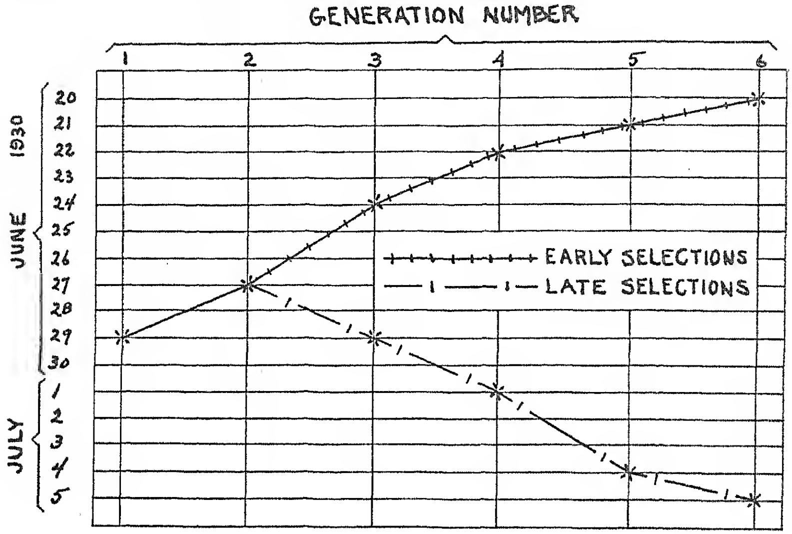

FIG. 3.—Average dates when the maximum percentages of timothy plants were in full bloom in plats of the third, fourth, fifth, and sixth generations selected for either earliness or lateness from six original selections.

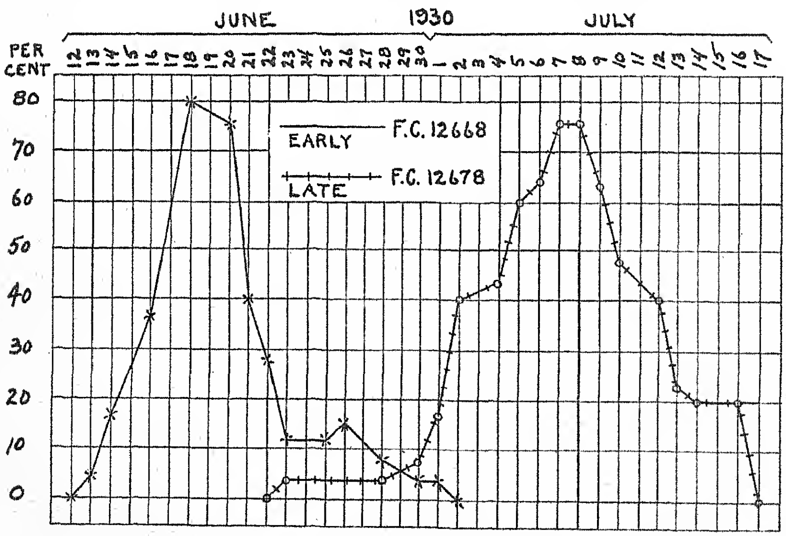

FIG. 4.—Percentage of timothy plants in full bloom on different dates in two plats after the fourth generation of selection for earliness and lateness from the same original plant.

SELECTION FOR GREEN LEAVES

In several seasons, estimates were made of the relative amount of green color remaining in the stems, leaves, and heads of the plants growing in broadcast plats of the late selections, when the ordinary timothy had nearly mature seed. The estimates were the averages of the ratings of several observers, using a scale ranging from 20 for ordinary timothy to 1 for plats in which all stems, leaves, and heads were dark green. In all late selections there were more green leaves and heads than in plats of ordinary timothy.

Table 1 shows the progress through four generations of developing strains which retain their leaves in a green condition comparatively late in the season. The first of this series, Huron timothy, each year has been rated considerably greener than ordinary timothy. In each successive generation the stems, leaves, and heads of the plants have been somewhat greener than in the preceding generation. This tendency to greenness has been correlated to a considerable extent with a gradually increasing lateness in the blooming and maturing of the seed. It has been shown (1) previously, however, that strains of timothy which bloom and mature together may differ in the percentage of green leaves.

TABLE 1.—*Relative rating for green color of unselected timothy and that selected for green leaves.*

Generations of selections	Rating for green color*		Average
	1931	1932	
Unselected	20.0	20.0	20.0
1st generation (Huron timothy)	16.8	14.7	15.7
2nd generation	14.5	14.3	14.4
3rd generation	13.1	13.7	13.4
4th generation	—	13.0	13.0

*A low rating signifies a high intensity of green color.

SUMMARY

The high variability in commercial timothy has made possible by continuous selection through several generations the development of strains having longer stems, earlier or later maturity, and better retention of green color in the leaves than the plants from which they were derived. The plants of many of these new strains show a high degree of uniformity, even though grown under natural conditions permitting open pollination.

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SMALL-GRAIN NURSERY EQUIPMENT[1]

HUBERT M. BROWN AND J. W. THAYER, JR.[2]

CHANGES in the size, shape, arrangement, and replication of small plats have necessitated changes in the methods used in the planting, harvesting, and threshing of the grain grown on such plats. Features of five machines now in use on the plant breeding plats at East Lansing and developed under a cooperative project between the sections of Farm Crops and Agricultural Engineering of the Michigan Agricultural Experiment Station are discussed in this article with the hope that they may be helpful to other workers.

Whenever a change has been made, it has been judged on the basis of (1) maintenance of purity, that is, freedom from mechanical mixture; (2) simplicity of operation; (3) efficient use of man power; (4) simplicity of construction; and (5) increase in speed of operation. The first requirement is the most essential and its importance is recognized by all. The other requirements are making themselves felt more and more as experiments are becoming more extensive and refined and expense is becoming more of a factor in planting, harvesting, and threshing.

MACHINES NOW IN USE

Planter.—Four planters, with force feed, were built in 1930 following some of the suggestions of Wiebe.[3] Three were built with small hoppers and one with a large hopper. The former require only 10 grams of seed to fill each machine so that it will begin to plant and are used for planting single rows or replicated plats of a few rows each. The large-hoppered machine is used for planting larger plats. The gears, shown at the right in Fig. 1, mesh as the head is dropped into place. A lever on the handle, within easy reach of the left hand, enables the head to be raised sufficiently to disengage the gears.

Seeds of wheat, barley, oats, rye, sugar beets, and kidney and pea beans have been planted satisfactorily with these drills. Some idea of the rapidity of planting may be gained from the fact that the 7,000 18-foot rows of the barley and oat nurseries of 1935 were planted in 16 to 17 hours, and the 1935 pea bean nursery of 1,350 30-foot rows was laid off, marked out, and planted in a 9-hour day, using these machines.

Cutter.—The present cutter, a one-wheeled garden tractor, was obtained in 1930. One of its regular attachments was a 39-inch oscillating cutter bar using standard sickle knives. A special hood was built over a modification of this regular bar so that it would allow one or two rows of grain to be cut per trip. Fig. 2 gives a side view of the assembly. Practice in the field proved that oats and barley which were standing well could be cut two rows at a time very nicely,

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[2]Research Assistants in Farm Crops.

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but this procedure could not be followed in wheat due to the height of the grain and the bulkiness of the bundles.

The drawback to the use of this machine is that it requires a 15- to 20- foot space for turning around easily at the end of the row. For most efficient use the machine should have a long traverse of cutting between turn arounds. The sections in the plant breeding field are

FIG. 1.—Hand seeder with head slightly raised.

302 feet across. Whenever possible, the field is laid out so as to allow the cutter to go all the way across the section. When this layout is not possible, a series of plats is cut out by hand to provide turn-around space.

The performance record of this machine is remarkable; its clean, rapid job of cutting, together with the compact, easily-handled bundle produced can be fully appreciated only by one who has seen the machine in operation. A five-man crew operates this cutter, the driver, one or two men to hold grain back in grooves, and the remaining men to take away the cut grain. Approximately 1,300 16-foot rows of wheat or 2,000 16-foot rows of barley or oats can be cut dur-

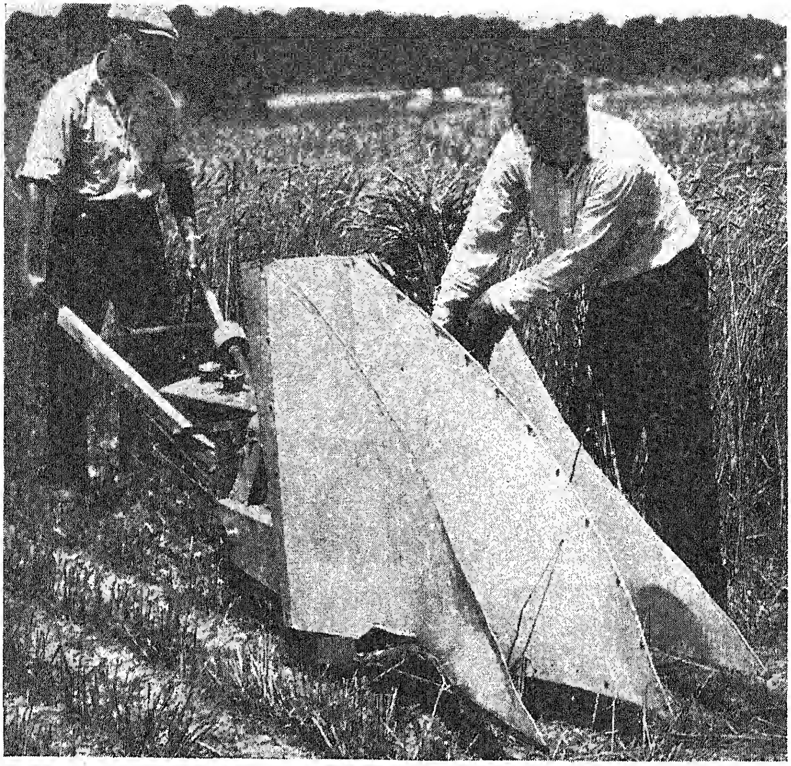

FIG. 2.—Garden tractor grain nursery cutter.

FIG. 3.—Completing the operation of bagging a bundle with the bagger.

ing a 9-hour day. The rate of cutting is greatly influenced by growth of seeded crop, by lodging, and last, but by no means least, by the ambition and efficiency of the operating crew.

Bagger.—This is a galvanized sheet-metal funnel, Fig. 3, and is used to aid in placing the paper bags (25-pound size, flat bottom type) over the heads of the bundles. If the bundle is small and compact, no bagger is needed, but when large, loose bundles are to be bagged, the funnel is a very great help and speeds up this operation materially. Two men work together to do this operation most efficiently.

Tier.—Since 1926, when rod rows were first introduced at the Michigan Station, tying the individual bundles has been a slow and expensive operation. In 1933, a commercial foot-power tier, Fig. 4, was obtained on trial and it so facilitated the work of tying the wheat, oats, and barley rod-row material that it paid for itself the first season.

The machine does not tie bundles as tightly as a binder because

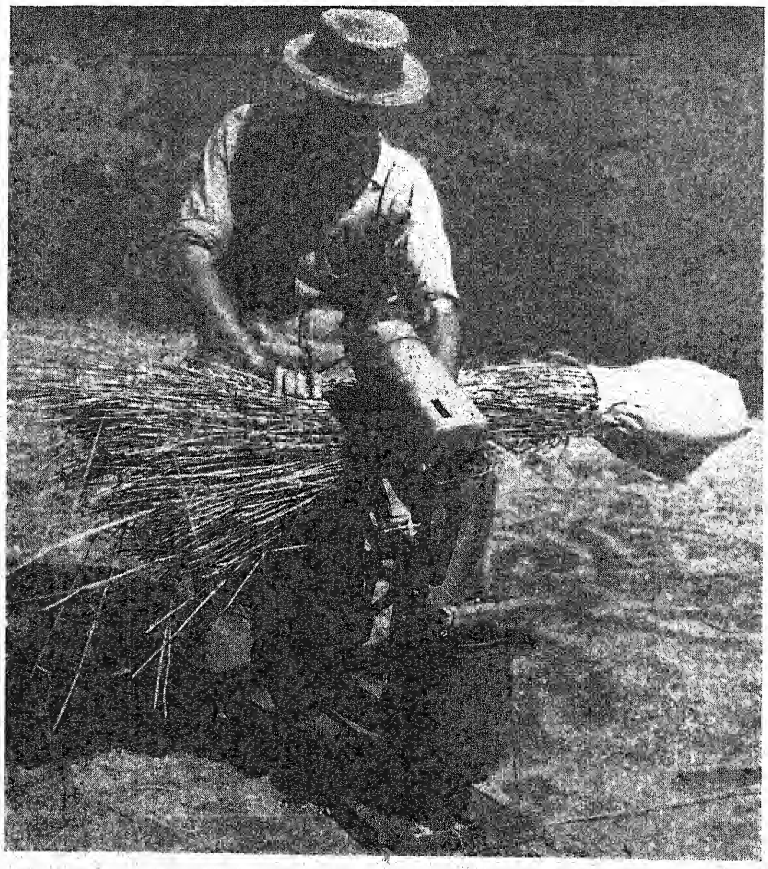

FIG. 4.—Putting the second tie on a grain bundle with the vegetable bunch tier.

there are no packers, other than the operator's hands. However, very little trouble is encountered with the grain slipping out of the ties, if the bundles are handled with reasonable care. This machine can conveniently tie the product from one 16-foot row of barley, oats, rye, or wheat. An 8-ply white cotton twine is used in the machine with a resultant material reduction in twine cost over the use of binder twine.

The crew needed is an operator, and for efficiency, two passers. The passer finishes tucking heads into the bag, pulls the bag as far down over the bundle as possible, squeezes the open end of the bag around the straw, and then passes the bagged bundle to the operator. The first tie is put around the open end of the bag and the second tie around the butt of the bundle. When two or more bundles are tied together, the work must be done by hand.

Nursery thresher.—A description of the several evolutionary stages in the development of this machine would fill many pages and has no place in this article. The easiest way to describe this machine, Fig. 5, is to follow the process through which the grain passes from the time that the bundle is placed on the table until the grain is packed in a carton ready for the laboratory.

The bundle of grain, with the bag string cut and the bag still over the heads, is placed on the table on the right side of the machine (Fig. 6). The butt string of the bundle is not cut unless the entire bundle is to be fed through the cylinder. The feeder takes the bundle from the table and, while the machine is being cleaned of the last variety, checks the number on the bag covering the heads with that on the bag that is to receive the grain. As soon as the machine is clean, the bag is pulled from the bundle and emptied into the hopper. The heads of the bundle are fed directly into the overshot cylinder. Spitting is minimized by having a special baffle of sheet-metal over the top of the cylinder end of the hopper. The baffles do not show in the picture. The grain and straw pass through the cylinder and fall to the bottom of the cylinder chamber where they are picked up by a strong blast of air from the upper fan. The strength of the blast is governed by a damper in the wind conduit between the fan and the cylinder chamber. The damper is set by test before starting plat material so that the strength of the blast will carry the grain and the straw well up into the riddle but will not carry the grain over the end of the riddle. When more air is needed to separate straw from grain in the riddle, it is readily supplied by depressing the lever under the feeder's left foot.

The grain and straw pass out of the cylinder chamber and on to the riddle. The riddle, which was used this year for wheat, rye, barley, and oats, has slits in the bottom, and it is through these slits that the grain, some chaff, and short straws fall. The bulk of the straw remains on top of the riddle and is blown out and over the end of the riddle. The grain and chaff which go through the slits fall onto a smooth piece of sheet-metal down which they slide to the cleaner.

In the cleaner, which has a glass window in either side for purposes of inspection, the grain and chaff fall into an up-draft of air from the lower fan. The grain falls on through into the grain chute and slides

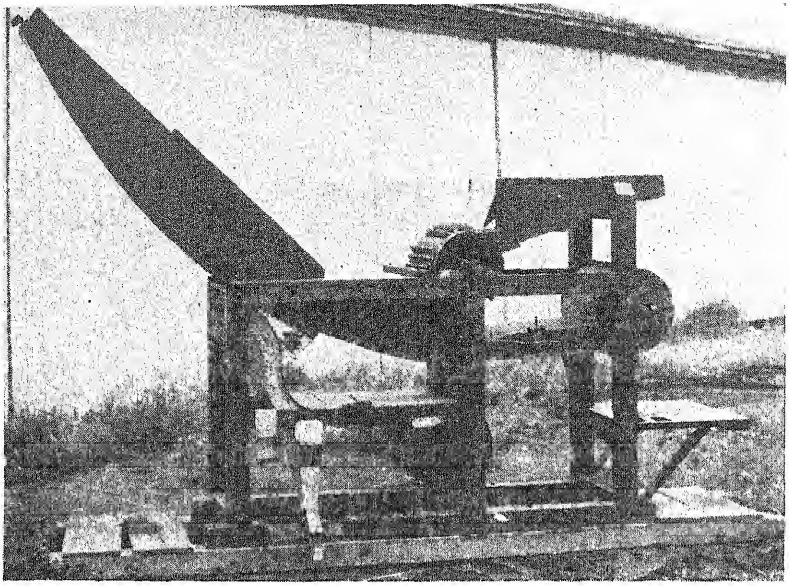

FIG. 5.—Side view of the nursery thresher.

into the envelope, bag, sack, or other container placed for it. The chaff passes on up and out of the cleaner along with the air. The force of the up-draft is regulated by a damper in the wind passage.

The entire machine may be cleaned between varieties in a few seconds by opening the air dampers to their maximum. The end of the grain spout is so fashioned that coin envelopes, 3½ x 5 inches, or

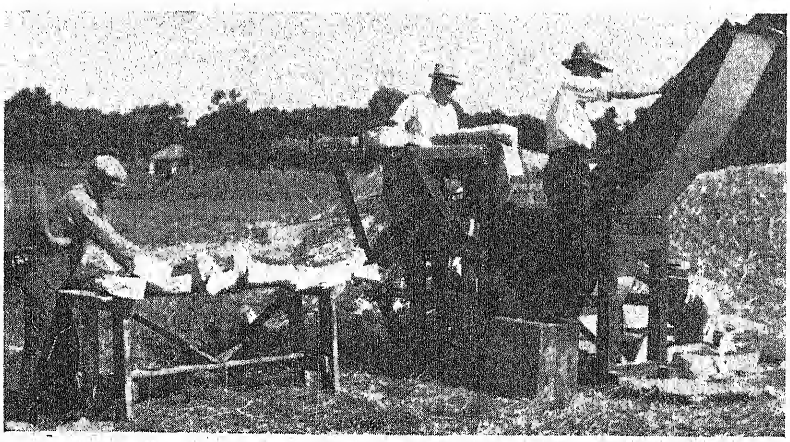

FIG. 6.—View of the nursery thresher in operation.

or 1-pound size paper bags may be as easily slipped over it as the larger sized bags.

This past summer 1,200 3-foot head rows of wheat were individually threshed and bagged in a 9½-hour day. Approximately that number of rod rows of barley, with three rows to a variety, were threshed in a day and the machine cleaned between each variety. Four men make up the crew, one to bring material to the machine, cut ties, and put it up on the table; one to feed, check number, and control the air on the riddle; one to keep the riddle clean; and one to take away the grain and pack it in boxes.

The bags of threshed grain are stacked in order in cartons and taken to the laboratory where they are weighed without further

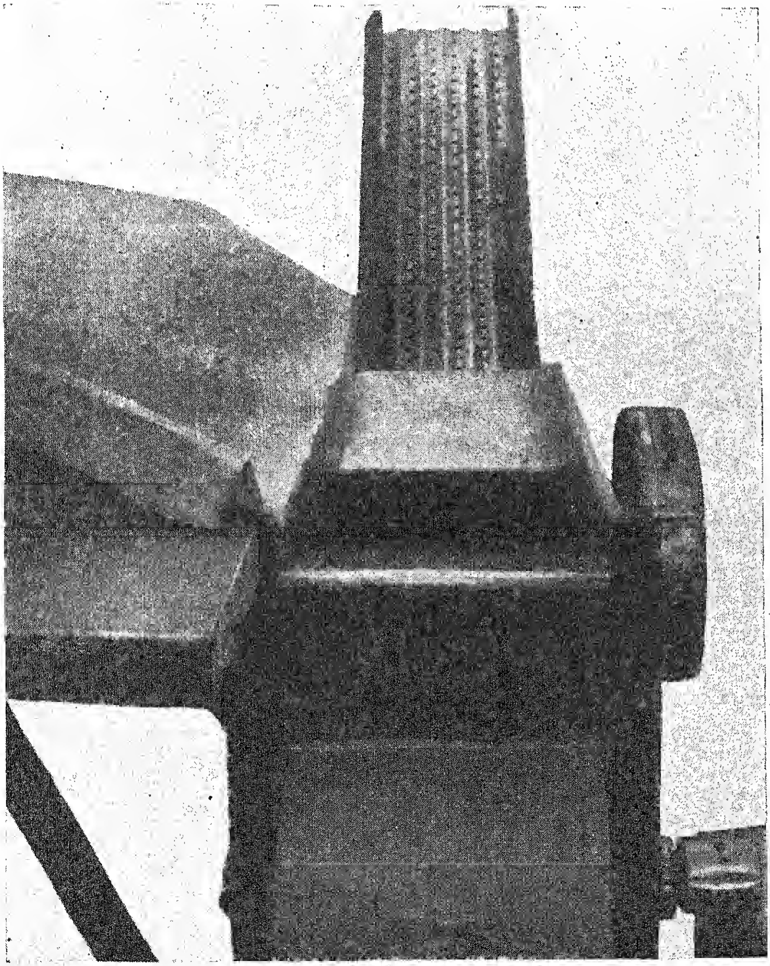

FIG. 7.—Looking at the bean thresher from the feeder's platform.

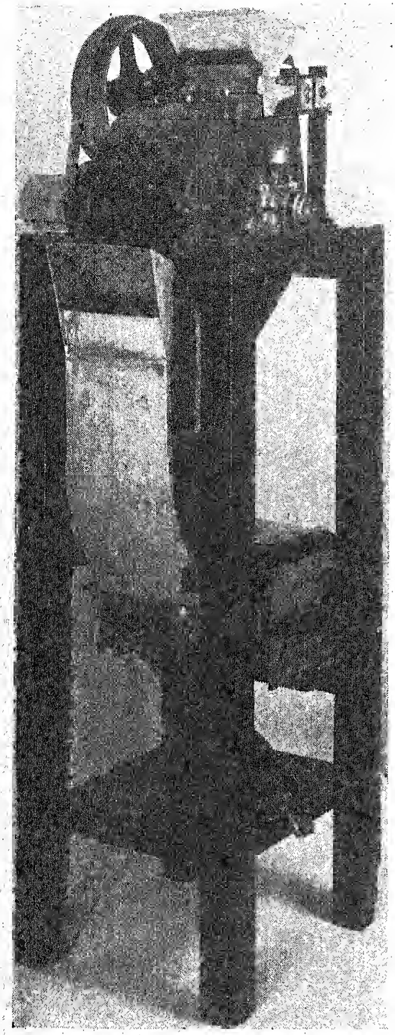

FIG. 8.—Head or single plant thresher.

cleaning. Samples that are to be used for seed are recleaned so as to remove any pieces of straw that might prevent free running of the grain in the drills.

The grain thresher is quickly converted into a bean thresher by changing cylinder, concave, and riddle and moving the table to the left side of the feed chute. The bean cylinder and concaves have round teeth instead of grain-thresher teeth and the cylinder is rotated much more slowly for threshing beans than it is for threshing grain. The riddle is a piece of corrugated sheet iron with half-inch holes punched in the troughs, Fig. 7. It is possible that this riddle will will work more effectively than the old one for the cereals, but it has not been tried sufficiently to warrant such a statement.

Head or single plant thresher.—The purpose of this machine is to expedite the tedious process of threshing individual heads or plants of cereals. The head or heads of a plant are fed into the funnel at the bottom of which are two rotating wringer rolls, Fig. 8. Old-style hard rolls are now used but are to be replaced by balloon rolls. These pull the head or heads into the cylinder and at the same time effectively prevent the loss of grain by spitting. The cylinder is of the overshot type and does a very excellent job of threshing. The bottom of the cylinder chamber is smooth and sloped so that it directs the grain and chaff into the cleaner. Here the threshed material falls into an up-draft of air through which the grain falls to the chute and into its container. The chaff is blown out of the upper end of the cleaner by the up-draft of air. The force of the air draft in the cleaner is regulated by slides on the end of the fan housing.

This machine has successfully threshed barley, wheat, oats, and rye and the threshed grain was so thoroughly cleaned that very little hand work was needed to reclean it. The lower end of the grain

chute is so fashioned that coin envelopes may be easily and quickly slipped over it. Two men, feeder and bagger, without crowding themselves and yet allowing plenty of time between samples to preclude mixtures, can thresh more than 2,500 single heads or plants in a 9-hour day.

This small machine has also replaced a much larger machine which was formerly used for preparing barley and oat samples for planting. For this operation it is very fast and 100% effective. One-pound samples may be cleaned at the rate of 50 or more per hour by one man operating the machine. Bulk grain may be cleaned at the rate of 4 bushels or more per hour.

Blueprints and specifications necessary for the construction of any of these machines may be obtained upon request from the Farm Crops Department, Michigan State College, East Lansing, Michigan.

PHOTOGRAPHY IN RELATION TO PASTURE INVESTIGATION IN THE SOIL CONSERVATION SERVICE[1]

R. F. Copple[2]

SINCE its beginning the Soil Conservation Service has attempted to make use of every available means which might aid in awakening the American farmer to the problem of erosion and enlist him voluntarily in a national program to conserve the soil. Not only does the farmer need to be enlisted in this program, but also a large percentage of those who are interested in conservation of our resources.

Not the least important of the *implements* at hand is photography, and the potency of the photograph has been constantly stressed as a means of emphasizing the acute need for action to combat erosion. Where the printed word may be drab and uninteresting, pictures tell a graphic and absorbing story—a story readable at a glance by everyone. Behind each photograph should be a reason for its existence. It should not, like Topsy, "just grow up".

Before a photograph is taken definite plans should be made to save both time and motion. Even with careful planning, however, there are a number of situations which lead a photographer almost to despair. One is unfavorable weather, but even that obstacle can sometimes be partially overcome by proper knowledge of photographic technic.

A number of suggestions are made here for those who use or take photographs. These suggestions do not cover the complete list nor are they expected to meet each particular situation or set-up for the photographer. The illustrations used in this paper are on pasture problems, principally in West Virginia and Ohio.

DEPTH OF FOCUS

One of the most important points to remember is depth of focus. This is accomplished best by stopping down the diaphragm to about 32 or less. This small aperture, of course, necessitates taking a much longer exposure. How long the exposure should be, depends upon the light, the film, and the subject. The value of a photo-electric cell for determining the exposure will be discussed under another section. A longer exposure tends to give clearer detail in the foreground, as well as in the background (Fig. 1).

Wind proves an aggrevation to the photographer because he can do little or nothing about it, except postpone the job, if convenient. In some regions the forenoon frequently has less wind than the afternoon. For objects like grain fields which are continuously in motion, an instantaneous exposure is the only choice. Close-ups of turf can be protected from the wind by circling the area to be photographed with about 15 feet of grass rug which may be 3 to 4 feet high, thus

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture. Also presented at the annual meeting of the Society, held in Chicago, Ill., December 6, 1935. As given at Chicago, this paper included about 30 slides on pasture management which were used to illustrate many of the points on photography. Received for publication February 21, 1936.

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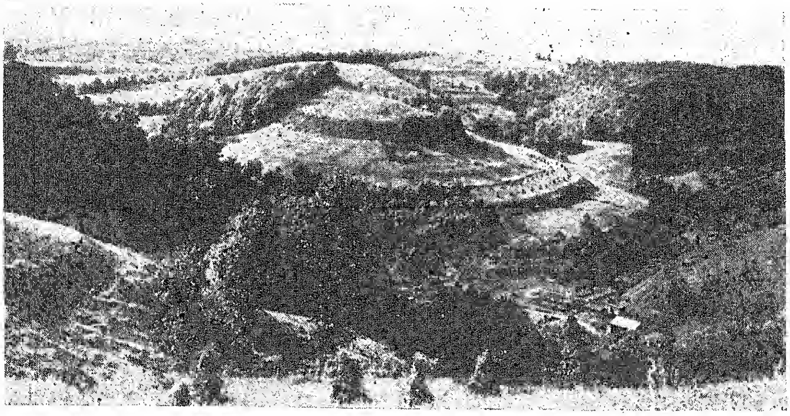

FIG. 1.—Depth of focus. Here the foreground as well as the distant objects are clearly in focus. Stop down the diaphragm and use a tripod.

temporarily protecting the area from wind while the time exposure is made. The tripod should be used constantly.

SHADOWS AND TIME OF DAY

The time of day when shadows are present is usually the best for photographs. The topography of the region frequently determines when a photograph should be attempted. When there is a bright sun, east and west slopes are usually best in the morning and afternoon, respectively. South slopes usually may be photographed best any time except at noon. The season of the year results in considerable variation in the color and shade of crops. The period when there is the greatest contrast in color will result in the best photographs. Shocked corn gives a good contrast. If the crops are similar in color, a filter may be used to advantage to get contrast.

The position of the photographer in relation to the subject may be used to advantage. Occasionally a shot toward the sunshine may bring out crop contrasts as one crop may give a reflection and be over-exposed while another may take normal, and thus result in a separation of the crops. The lens should be protected from the direct rays of the sun at all times. This may be done with the slide or with a metal shade which is constructed to fit over the lens.

On a clear day in woodland, it is almost impossible to eliminate sun spots which filter through a dense foliage. Where detail is desired, especially of the duff, roots, or soil profile, thin clouds are especially useful. Where close-ups are needed of bark characteristics, when the sun is shining directly on the object, take the photograph at a right angle to the sun, thus utilizing shadows to advantage. The time of the exposure should not be based on the brightest nor the darkest part of the subject but on an average as most films have considerable time latitude.

SOIL PROFILES

Soil profiles are usually easier to photograph along road cuts. Slice off the weathered slope down to where the soil is not discolored.

In fields and pastures a pit may be dug about 2 feet wide and 18 inches deep with a moderate slope from the ground surface toward the back. This pit or side of the profile is best if facing the sun in order to make it convenient for the cameraman to shade the profile. The back of the pit should not be vertical but should slant back to permit the camera to shoot straight into the soil profile, and thus be in focus from top to bottom. The swingback on the camera may be used to square up the sides, but this usually is used for buildings. Usually it is desirable to shade the soil pit if possible when the sun is bright. The separation of the soil horizons is made by scratching a furrow between them, as the colors and texture are frequently quite similar and impossible for the camera to separate. An 18-inch ruler is handy to show the depth of the profiles. A steel tape is also convenient for deep profiles.

THE BACKGROUND

Frequently the object to be photographed blends so well with the background that some object is essential in order to get a contrast. An automobile, a man, or other object may be used. Cameras which have a delayed timing device which permits the camerman time to get into the photo have merit. Most photographs need a touch of the human element to give them life, employ contrast, and provide a measuring stick for comparison.

FRAME OF THE PICTURE

An artist is cautious when he selects a frame for his painting. The same care is essential for general views in photography. If possible, utilize a tree trunk, dead limb, or similar objects to serve the purpose (Fig. 2).

Fig. 2.—The frame of the picture is important as shown in this black locust-Kentucky bluegrass pasture. A tree trunk or dead limb can be utilized.

TOPOGRAPHY OR SLOPE

In the Soil Conservation Service we are constantly dealing with slopes and run-off, especially in our land utilization program. For practical purposes we can make use of some common implements to serve our needs. In woodland use a tree trunk at one side of the picture or one located in the distance. For fields use a man, the team at work, a perpendicular stake, camera case, or similar objects to show slope (Fig. 3). All of these should be on the level or same contour as the camera, because a photograph taken up or down hill usually gives ambiguous impressions especially as to the amount of slope (Fig. 3).

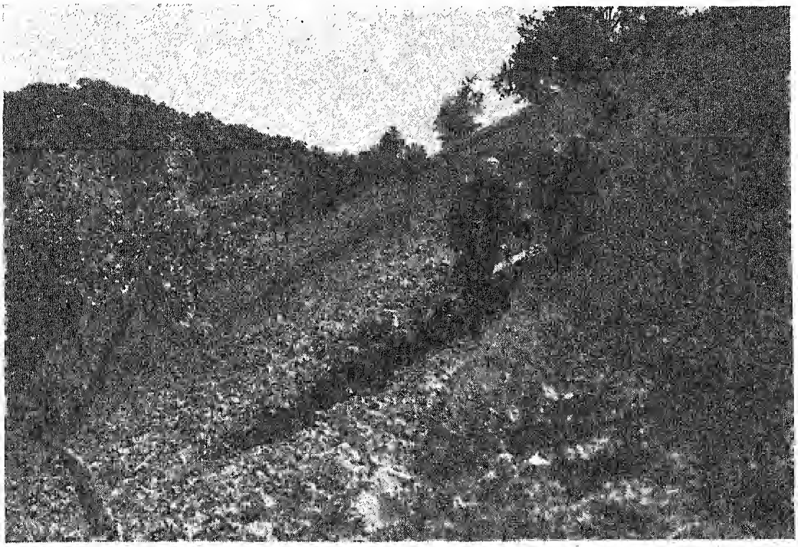

FIG. 3.—This 30% slope is shown well by the team and also by the apple tree on the right.

THE PHOTO-ELECTRIC CELL

Through experience considerable accuracy may be developed in regard to the time of exposure and size of aperture necessary for each photograph, however, there are times when we fail completely, usually in the photograph needed most. We are dealing with considerable variation in conditions and especially is this true of soils, light, vegetation, season, and topography. The time of exposure necessary in the regions of the Southwest, such as the Gila and Navajo projects, will likely be different from that in the Aroostok potato area in Maine or the Pullman region in eastern Washington, even though the subject may be quite the same. The photographic equipment used is generally accurate and likewise valuable. It is necessary to make the best use of it as well as of the available time. The photoelectric cell is easy to manipulate, compact, accurate, and does not guess.

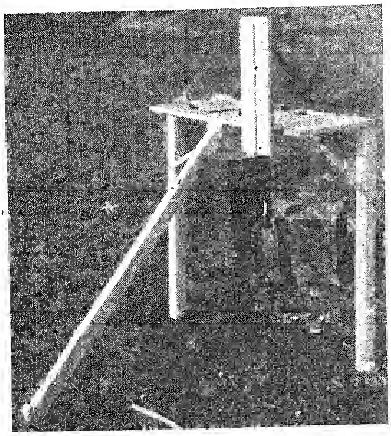

FIG. 4.—A folding table for taking turf photographs in pastures. It is adjustable for height, is economical in cost, and is well adapted for making "retakes" of the same area from year to year.

FILTERS

There are various filters available, but usually if only two or three are used discreetly much better results are to be had. The K2 or yellow filter is best adapted to orthochromatic films. On panchromatic or similar films all filters may be used. The red filter seems to have the widest use, however, it is not satisfactory for films such as orthochromatic which are not sensitive to red. The camera should be focused with the filter attached. The time of exposure will vary according to the type of filter used.

METHODOLOGY

In pasture investigations there are a number of methods used to record the change of turf or vegetation, such as the ocular estimate, the quadrat count and the pantograph. Most of these records are influenced by the personal factor. In many instances it is thought that the photograph may be utilized to eliminate some variations frequently attributed to the recorder.

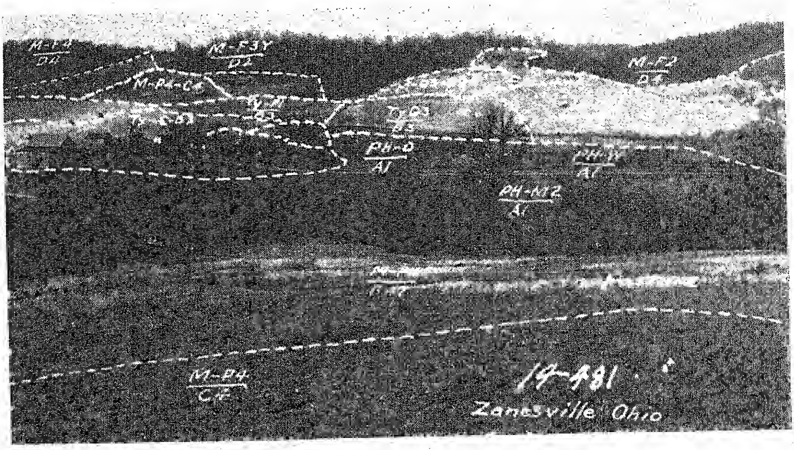

FIG. 5.—Land use shown on a photograph by inking in the soils and designations. For example, in the foreground the symbol $\frac{\text{M-P4}}{\text{C4}}$ is translated as follows: Soil, crop, slope, and erosion with M = Muskingum silt loam; P4 = Pasture with less than 10% desirable species; C = 20 to 30% slope; and 4 = over 75% of the surface soil lost.

11 Swingback 834

PHOTOGRAPHERS B.I.S. J.W.S.

DATE 9/18/35 Green Filter

TIME 9:45 A.M. STOP 32 EXP. 3 sec.

WEATHER CONDITIONS Clear

COM. PAN. LIGHT 100

COUNTY Wirt

TOWN

LONGITUDE 38

LATITUDE 81

DIRECTION AND DISTANCE FROM NEAREST TOWN

1 Mi. S. of Palestine on Highway 14 West of Road

LAND OWNER OR OPERATOR

NAME Isophene Morehead

ADDRESS Palestine, West Va.

REFERENCE TO PERMANENT LAND MARK

Taken S. 20 E. approx. 50 Ft. below 12″ walnut (Blazed)

PHOTOGRAPHER'S POSITION Looking down on lespedeza seeded in contour furrows.

SUBJECT Agronomy

Pasture Management

Contour Furrows

History: Lespedeza was seeded on these contours in March 1935. Note heavy stand obtained. These furrows were also treated with superphosphate and stock naturally grazed the fertilized ridges. When the soil is wet tramping may permit the water to break thru. This may not become serious if the water is caught in the lower furrows. It is recommended that fertilizers be placed between the strips also in order to prevent damage to the furrows.

NOTE: This picture is of no value without exact locations shown.

FIG. 6.—A suggested photograph record.

For turf or close-up studies of vegetation, a folding table has been constructed which is economical, saves time on retakes, and can be adjusted to take vertical phtographs from a height of 36 inches down to 12 inches or closer to the subject (Fig. 4). The area photographed depends upon the height and type of camera, but areas from 20 by 30 inches down to 5 by 7 inches are possible. The changes in vegeta-

tion on the same plat or quadrat may be photographed from year, to year, or more frequently if desired, by using permanent markers.

RECORDS ON THE FILM AND PRINT

The Soil Conservation Service is dealing not only with soil and water conservation but also with better land use. After the soils boundaries have been mapped, we can transfer them on a film for reproduction on a print. The present land use can also be outlined on the film by using opaque ink. We can show on the photograph the present as well as the recommended land use. Opaque ink is more desirable than India ink, as it can be easily removed from the negative if necessary. The ink should be placed on the shiny side of the film (Fig. 5).

THE RECORD

The photograph record is essential. It should be complete. There have been too many photographs taken with incomplete records (Fig. 6). One good photograph is worth a hundred poor ones. However, one may have a good photograph but in order to get the whole story, a "retake" is frequently necessary. To make a "retake", it is essential to go back to the original set-up. Occasionally, it is possible to use the "hunt and fit" system by duplicating the topography, trees, or other permanent land-marks with the original photograph. This is an unnecessary loss of valuable time, even if successful. If the photograph is a "close-up" turf of a terrace outlet or a contour furrow in the pasture, however, the chances are that the original place of the "set-up" will never be located even by the person who made the original photograph, how then does one expect another to find the location without some guide?

Locate the "set-up" with a permanent marker if possible. A rock mound, an iron stake, a conspicuous tree which is blazed, a bridge, a building, a fence corner, or similar marker. Occasionally these may be moved, but they are usually permanent. Wooden stakes usually rot off near the ground. An iron stake is more permanent, but if driven in a meadow where the mower may be broken, future relationships with the farmer may be strained. Then it is essential to take a record of direction with a compass and pace the distance to some permanent landmark. A "repeat" photograph after all is a pictorial barometer of the success of our work. A good picture requires time and patience, but it is worth it.

THE USE OF RAPID SOIL TESTS IN THE UNITED STATES[1]

R. P. THOMAS[2]

A QUESTIONNAIRE pertaining to the use of rapid soil tests was prepared by the Sub-committee on Soil Testing of the general Committee on Fertilizers. Copies of this were sent to the deans of the agricultural colleges and to the experiment station and extension directors in each state, with the request that they be placed in the hands of all who were concerned with such tests. At least one reply was received from every state, with some states returning as high as six filled in questionnaires. It was difficult to determine the exact nature of the work in a few states due to contradictory answers. Some states simplified their replies by returning one questionnaire for all concerned with rapid soil testing. A summary of the information obtained in this survey is presented here.

USE OF TESTS BY STATES

Five states, namely, California, Nevada, Arizona, New Mexico, and Florida, reported no use of the rapid soil tests. The reasons given varied from that of lack of funds to unsatisfactory results with those tried. Seventeen states reported only a limited use of such tests. It is interesting to note that most of these states are located in two sections, namely, the southern Atlantic and Gulf states and the northwestern states east of the Rockies. The reasons given for the limited use of rapid tests were many. The principle ones were lack of funds or personnel to carry out the tests, no means of checking the results against soils of known fertility, very little demand for this kind of work, and the belief that a good observer in the field could guess as well as the one making the determinations. The remaining states reported extensive use of many different kinds of rapid tests. These states lie primarily in the central western area, the corn belt section, and the eastern Atlantic states. Most of these states indicated this kind of work was done rather extensively in order to give better advice and service to the grower and farmer. The use of the rapid soil tests as presented by the returned questionnaires is charted by states in Fig. 1. The states in which no cross hatching appears reported no use of the methods. Limited use is shown by the vertical lines and extensive use by horizontal lines. The meaning of the terms limited and extensive was not definite. Limited seemed to indicate that not many of a single test or only a few of many of the different kinds of tests were made. Extensive was used when a large number of single tests or many different kinds of tests were made on the individual samples.

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[1]The material presented here was assembled and prepared by the author upon the request of the late Dr. N. A. Pettinger, Chairman of the Sub-committee on Soil Testing of the general Committee on Fertilizers of the Society and was first reported upon at the annual meeting of the Society in Chicago, Ill., December 6, 1935. The report was submitted for publication upon request of the Sub-committee. Received for publication January 28, 1936.

[2]Associate Professor of Soil Technology, University of Maryland, College Park, Md.

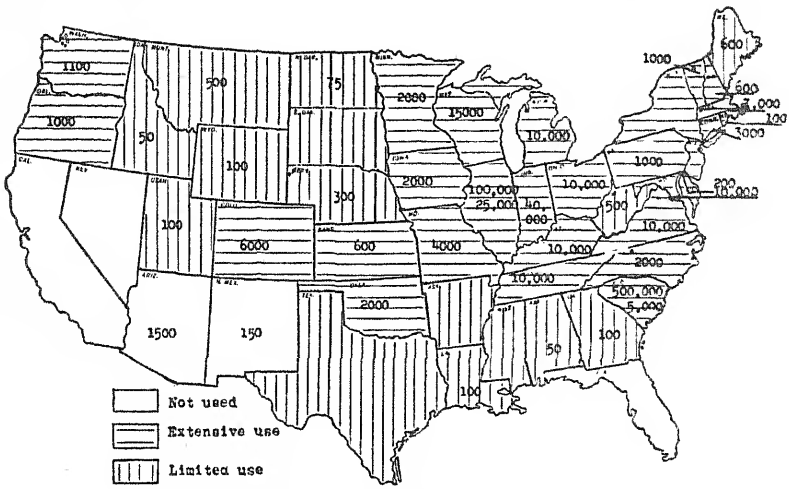

FIG. 1.—Use of rapid soil tests by states and the number of samples tested annually.

Many different kinds of tests and procedures were reported in use. Some states were using several different methods for the same elements. Frequently, the returned questionnaire did not contain complete data as to the methods used. A few states listed the regular long and routine laboratory procedures with a cost as high as $10 per sample as being used to estimate the lime and fertilizer needs of samples received. The methods and details varied so by state and even within some states that it was impossible to tell exactly the methods used by some workers. The summary was made by individual tests, such as pH values, lime requirement, phosphorus, and potassium, instead of by methods. The replies to the other questions were grouped as much as possible under similar headings.

pH VALUES

Soils were tested for their pH value more than for any other determination. This is shown by the horizontal lines in Fig. 2. Forty states were making these determinations. Even states which reported no use of rapid tests stated that they were making many pH tests largely as an indication of alkaline conditions. Arkansas, Florida, Illinois, Iowa, Missouri, Utah, Washington, and Wyoming did not make any pH determinations on the samples submitted by the farmer.

The pH values were determined for the most part by various modifications of the colorimetric methods. No one of these modifications seemed to predominate over the others. In addition, many states used one or more of the various commercial tests for pH determination. The commercial pH tests arranged in order of decreasing use were Truog-Hellige, LaMotte, LaMotte-Morgan, and Soiltex. Ten states reported the use of some form of electric potentiometer. Only one state reported the use of the glass electrode, although it is known that other states are using it.

LIME TESTS

Most of the states which did not make pH determinations used some form of lime requirement. Twenty-five states, as shown by the vertical lines in Fig. 2, reported various kinds of such determinations, the most consistent one being various modifications of the thiocyanate tests. Several used the commercial product known as Rich-or-Poor, while many made their own. Six states reported the Truog

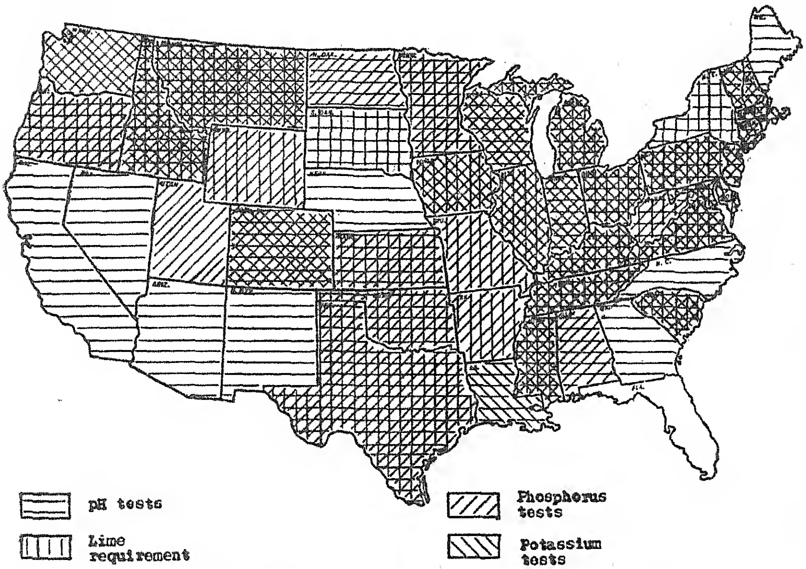

FIG. 2.—Use of rapid soil tests for pH value, lime requirement, phosphorus, and potassium by states.

lime requirement test still in use. Often there was considerable difference between the methods used by different departments within a state. That is, the extension staff and county agents would be using one or more kinds and the experiment station workers still others. Only one state, Washington, which used the rapid tests, made neither pH nor lime requirement determinations.

PHOSPHORUS

The results of the reports for phosphorus indicated this element was deficient in most soils. Thirty-six states reported the use of one or more methods for determining such deficiency. The largest interest seemed to be centered in the middle western and eastern states, although all of the northwestern states make these tests. This is illustrated by the diagonal lines sloping to the right in Fig. 2.

For brevity, the weak acetic acid extraction for deficiencies and the various sodium acetate extractions will be called the Spurway and Morgan methods, respectively. Sixteen states located mostly east of Ohio, reported the use of various modifications of these methods.

The stronger extracting solutions, such as the Bray, Truog, and their respective commercial products, were used in 21 states. These methods were used for the most part in the states lying west of Ohio, although several of the states using the weaker extracting solutions used one or more of these tests for some soils. While 13 states indicated the use of the Bray procedure, only 7 of these used it alone. Thirteen states indicated the use of the Truog method with only five depending solely on this method. The various modifications of Morgan's method were used in 14 states with only 8 using it exclusive of any other phosphorus test. The Spurway phosphorus tests were made in five states but only two states relied entirely on it. The Purdue or Thornton phosphorus method was used in two states. Four states, namely, Colorado, Montana, Oklahoma, and Texas, reported special phosphorus tests of their own. These varied from the various biological tests to special modifications of some of the other tests. Twelve of the 36 states used two or more methods for determining phosphorus needs.

The results of these reports indicate that no one method seems to be entirely satisfactory for all cases. The various modifications of the sodium acetate extractions seemed to be in use more than any other phosphorus tests. This was largely confined to the eastern part of the United States.

POTASSIUM

If the results of the questionnaire can be used as a criteria, the need for potassium is not as great as phosphorus or lime. Only 24 states reported making this test. Of this number, several states made them only on request. The central corn belt, northeastern, and central Atlantic states carried on the most of these potassium estimations. Eleven states reported the use of Morgan's method and 8 of this number depended entirely on it. The Spurway procedure was made in seven states with only three depending entirely on this test. Potassium needs were detected in eight states by Truog, Bray, LaMotte, and Thornton methods. Each method was used by two different states.

OTHER TESTS

Determinations for soluble calcium and magnesium were reported for 20 states. These states were largely those in which the Morgan or Spurway methods for phosphorus and potassium were used. Such tests were centered largely in the east central and northeastern sections of the United States. A few states indicated that determinations were made for these elements occasionally and only on request. Organic matter determinations were made when requested in 10 states. Although these 10 states seemed to appear at random in the United States, the largest number was in the northeastern section. The methods in use varied from that of combustion to various modifications of the rapid titration methods. Special tests for nitrate nitrogen were used in 10 states exclusive of those doing the Morgan or Spurway tests. These states were not confined to any special section of the country. Alkali tests were made in most of the western

states. Eight states reported specific alkali tests, although many states indicated that they obtained something as to the alkali condition by the use of other tests. These rapid tests are supplemented by plant tests in 14 states. In many of these states the number of plant tests was not large, as the opportunity of obtaining the material for such determinations was limited. Some indicated that it probably would be desirable to make these plant tests, but that it was impossible to do it.

NUMBER OF SAMPLES

Nine states reported no record kept of the number of rapid determinations made. This is shown in Fig. 1 by the states which have no number in them. In order to get a better picture of this situation, the states have been grouped according to the total number of tests reported. Thirteen states reported 500 or less tests during the past year. These states were Alabama, Delaware, Georgia, Idaho, Kansas, Louisiana, Montana, New Mexico, North Dakota, Rhode Island, Texas, Utah, and Wyoming. It will be noted that most of these states are in the western and southern part of the country. Three states, namely, Maine, New Hampshire, and Pennsylvania, reported between 500 and 1,000 tests during the past year. Eight states indicated they made from 1,000 to 2,000 such determinations. These states are Arizona, Iowa, Minnesota, North Carolina, Oklahoma, Oregon, Vermont, and Washington. Only two states report more than 2,000 and less than 5,000 tests for 1934. They are Connecticut and Missouri. Five thousand to 10,000 rapid soil tests were reported for Colorado, Maryland, Massachusetts, Michigan, Ohio, South Carolina, Tennessee, and Virginia. The totals for South Carolina and Virginia are exclusive of the lime or pH tests. There is an indication that if these tests were included the figures would be much higher. Four states reported more than 10,000 tests during the past year, including South Carolina with 500,000 for pH, Illinois with 100,000 for lime requirement and 25,000 for phosphorus, Indiana with 40,000 rapid soil tests, and Wisconsin with 15,000 determinations. In these states which reported the highest number many of the tests were for single items such as pH value and lime requirement. The eastern corn belt states seemed to be the center of the rapid soil testing. if numbers can be used as an index. The central Atlantic states indicate another center. If the tests were based on the number per farm or square mile of tillable land, this latter area would undoubtedly be the greatest center.

COSTS

The estimation of the costs was from a fraction of a cent to \$10 a sample. Since the cost was figured in many different ways, it was impossible to make any average. Many reported the cost for chemicals or solutions alone and others included the cost for labor in addition. Different states indicated the use of the same methods, yet the cost varied considerably. Where single tests, such as pH or phosphorus, were made, the cost was nearly always much less than that where a series of elements was estimated. A majority of the estimates fell between 10 and 50 cents per sample.

TESTING SERVICE

The reply to the question pertaining to the personnel or to the position and employment of those making the tests indicated that for the most part they were made by the experiment station and teaching staff. Only two states, Michigan and Vermont, reported the work being done entirely by the extension service. There were 18 states in which the extension staff cooperated in this service. All of the testing was done by the experiment station or teaching staff in 20 states. This same group of workers assisted in making the tests in 20 other states. The county agents made most of the tests in North Dakota. They were also important members of the testing staff in 15 other states. Agricultural teachers in the various vocational schools did some soil testing in 18 states. Only six states reported much of any testing by commercial companies. It is doubtful if this is the true picture of the situation since a large number of workers in another portion of the questionnaire indicated they served as advisors for commercial representatives in rapid soil testing. It would seem that for the most part the responsibility of soil testing falls upon the experiment station and teaching staff.

In this connection it is interesting to note that, although the extension service was solely responsible for this service in two states, they financed it entirely in six states. Thirty-nine states indicated that it was under the supervision of the experiment station and teaching staff, with the extension service cooperating in paying the bill in nine of these states. In 25 states the cost was borne entirely by the experiment station and college departments. The departments concerned with rapid soil testing were agronomy, bacteriology, chemistry, botany, and soils. The replies indicate that very few of these states wish to pass this cost on to the farmer or layman, as 40 states made no charge for this service. In four states, namely, Colorado, Maryland, Montana, and Tennessee, a charge was made under certain conditions. This varied from 25 to 50 cents per test. It seems as if a charge was made only to commercial companies and large farm organizations.

The trend of the replies to the question pertaining to method of handling this service in the different states indicates a growing tendency toward centralization or absolute control of rapid soil testing by having it done at one place under the supervision of specially trained men. Five states indicated that under the present conditions this service could be handled better by field men or agents rather than to have all tests made in one central place. Under these conditions the experiment Station or extension staff regulated the service by supplying the testing reagents or designated the ones to be used. Twenty-three reported some training being required for the testers. The requirement indicated by most of these 23 was nothing other than a college degree. Fifteen states indicated that they encouraged the county agents, agricultural teachers, and commercial men in making the tests. Eight states reported a similar encouragement but only to a very limited extent. In 23 states there was no encouragement at all. Most of these states indicated that they did not believe in such encouragement.

It is interesting to note that 30 states reported either no testing by fertilizer or similar commercial companies in the state, or if it was done, it was without the sanction of the experiment station. Seventeen states reported that they were unofficially acting as advisors or helping the various commercial men who are making the tests. There were a few states which reported that testing by commercial men was encouraged. Many expressed the belief that it should be encouraged if the tester was conscientious. Some reported that much of the testing by commercial representatives was biased or not properly done and for that reason none of it should have the sanction of the experiment stations.

INTERPRETATION OF RESULTS

It seems as if the majority of the states recorded the results of their rapid tests by symbols or letters. These were sometimes changed to pounds per acre before being sent out to the farmer with recommendations. Even though many of the states were very strongly in favor of and placed considerable value on these rapid tests, they desired from the one submitting the sample much more information before interpreting the results. Many indicated such data as valuable, if not more so, than the results of the rapid tests. The things considered in addition to the results of the tests were grouped under four headings, *viz.*, soil information, crop record, economic conditions, and the personal element. Under soil information the following items were listed as being used as supplements to the tests in making recommendations to the farmer: Soil type, origin, chemical analysis, exchange capacity, fertilizer response, plat tests, demonstrational farms' results, pot tests, organic matter, drainage, topography, fertilizer, and lime treatment. The following desired facts to support the tests were classed under crop record: Kinds of crops, crop yields, crop rotation, livestock produced, climatic conditions, plant behavior, and visible symptoms of plants. The following suggestions were included under the heading of economic conditions: Type of farming, market, source of farm income, operated by owner or tenant. Under personal element the following things were indicated as being very valuable factors to consider: Type of man, common judgment, experience of agronomist, guessing, and prejudice. This information was obtained in nearly every way possible. Most states reported that it was secured by letter or questionnaire, although sometimes by visits either to the farm or the farmer to the laboratory. Often it was very difficult to obtain any reliable information from the layman.

SOIL SAMPLES

The question pertaining to the treatment which the soils undergo in the laboratory was not very well answered. Most of the states which replied indicated that the samples were either air-dried or partially air-dried. Some stated that the samples were screened, although several stated they were only mixed. The 20-mesh screen seemed to be the most popular, although everything from 10- to 60-mesh was suggested as being in use. About half the states indicated that the samples were run as soon as received. In most of the other

states they were allowed to accumulate until a large number were on hand, then the determinations made. Thirty-one out of the 36 states replying to the question pertaining to the sampling and testing of subsoils indicated that such samples were secured only occasionally. Some desired subsoil samples along with the other samples largely to aid in identify the soil. Some states indicated they had carried on extensive studies in comparing the rapid tests with field response to fertilizer and lime treatments. Most states indicated that this had been done only to a limited extent. The information received regarding the preparation of the samples and standardization of the test suggest the need of more uniformity and coordination if the work in the different states can be compared.

FUTURE OF SOIL TESTING

The demands for this service and the opinions on values of the tests in use were answered by practically every state. Forty-two states indicated that such demands were increasing and six of these stated that the increase was very rapid. Even in the states not making such determinations at the present the demands for this service were increasing. Four states, Kansas, Minnesota, New York, and Utah, reported that there was neither an increase or decrease and one state, Alabama had a decrease in demand for this service. Since 22 states expressed the belief that the tests in use at the present were unsatisfactory or inadequate, there is an indication that there is much need for improvement. Twelve states reported that the present tests were fairly satisfactory and 6 that they were practically satisfactory. These last 18 states are largely those in which the largest number and more complete tests were made. For the most part the unsatisfactory experience with the rapid tests were from the states which reported only a limited use of these methods.

SUMMARY

The reports to the questionnaire prepared by the Sub-committee on Rapid Soil Testing and sent to all states indicated the following conclusions.

The use of rapid tests for determining soil deficiencies is extensive. The middle western, east central, central Atlantic, and northeastern states seem to be the most active in this work.

The tests for pH value was used more than any other single determination.

Lime requirement determinations were made in many states even though pH determinations were made.

The estimation for phosphorus deficiency was made in two-thirds of the states. Many of these states used more than one method which indicated that at the present time no one method is entirely satisfactory.

The rapid determination for potassium was much more limited. The corn belt states, east central, central Atlantic, and northeastern states were the centers for these tests.

Very few states made separate tests for calcium and magnesium unless it was included in the method used in making other determinations.

Organic matter, nitrate nitrogen, alkali, and plant tests were reported as being made occasionally by some states. The eastern-corn belt states made the largest number of rapid soil tests, with the central Atlantic states a close second.

It is very difficult to determine the cost since the methods of reporting varied considerably.

The responsibility of the rapid soil testing fell for the most part on the experiment station and teaching staffs. County agents and agricultural teachers made a large portion of the tests in some states, although many states indicated that this was not very desirable.

For the most part this service was financed by the experiment station or college, although in some cases the extension service bore all of the expense, while in others it was cooperative.

Practically every department which does any soils work reported some work with rapid tests. Due to the unsatisfactory results of the tests often reported by the different workers, the majority believe that centralization of the testing in one or two places in each state would be better. Commercial companies on the whole are not encouraged to offer this service to the farmer.

Most states reported the results of their tests in letters or symbols. It seemed to be more desirable to send the interpretations and recommendations based upon all obtainable information rather than the results of the tests alone.

The results indicated that there needs to be considerable collaboration on the treatment of the soil samples and interpretations of the tests made before a comparison of methods can be made. At the present time the most of the states indicated that the rapid tests have been checked under field conditions only to a limited extent. The demand for the use of these tests is increasing rapidly. Since these tests are based on fundamental research and are limited in themselves, very few workers felt that a state of perfection in rapid soil testing had been reached.

AGRONOMIC AFFAIRS

STUDENT SECTION ESSAY CONTEST

THE American Society of Agronomy has agreed to sponsor the student essay contest inaugurated several years ago by the Committee on Student Sections. For the best papers submitted three prizes will be awarded as follows:

1. $15.00 and 1 year's subscription to the JOURNAL.
2. $10.00 and 1 year's subscription to the JOURNAL.
3. One year's subscription to the JOURNAL.

Essays must be prepared by undergraduate students. Papers should be typed, double-spaced, and not over 3,500 words in length. Abstracts should be included as it is hoped that the winning papers may be published in abstract form in the JOURNAL.

Any one of the following topics may be used:

1. Pasture Improvement in the United States.
2. Controlling Noxious Weeds.
3. Breeding for Disease Resistance as a Basis for Improving Farm Crops.
4. The Importance of Soil Conservation.
5. Soil Water in Plant Growth.
6. The Rôle of Some Nutrient in Crop Production.

Papers must be in the hands of the Chairman of the Committee on Student Sections, Dr. H. K. Wilson, University Farm, St. Paul, Minnesota, not later than November 1, 1936.

PROGRAM FOR MEETING OF THE NORTHEASTERN SECTION OF THE SOCIETY

THE following program has been arranged for the meeting of the Northeastern Section of the Society which is to be held at the West Virginia Agricultural Experiment Station, Morgantown, West Virginia, June 24 and 25.

WEDNESDAY, JUNE 24

8:30 A. M.	Assemble at Oglebay Hall (Room 204)
9:00 A. M.	Agronomy Farm:
	Corn breeding
	Sweet clover breeding
	Small grain nursery
10:30 A. M.	Animal Husbandry Farm:
	Response of pasture to fertilizers and lime
	Response of alfalfa to fertilizers and lime
12:30 P. M.	Lunch at University Cafeteria
2:00 P. M.	Reedsville Homestead Project:
	Response of potatoes and corn to fertilizers
	Cooperative potato fertilizer experiment
6:15 P. M.	Banquet and Business Meeting (place to be announced):
	Welcome, President C. S. Boucher
	(Introduced by Dean F. D. Fromme)

Response, J. A. Bizzell, President, Northeastern Section
Business Meeting
Announcements

THURSDAY, JUNE 25

8:00 A. M. Start for Lakin, W. Va., via Ohio River road
11:30 A. M. Lunch at Parkersburg
1:30 P. M. Arrive at Lakin, W. Va.:
Inspect field plats
Response of various crops to fertilizers and green manures
Response of tobacco and legumes to various pH levels
Crop rotations
Lespedeza plats
Tobacco breeding
Watermelon breeding
(Field experiments with vegetables are also located at Lakin)
5:00 P. M. Adjournment

It is expected that arrangements will be made at one of the University dormitories to accommodate visitors Tuesday and Wednesday nights, June 23 and 24. If preferred, excellent hotel accommodation may be obtained in Morgantown at reasonable rates. For those who desire to visit the pasture experiments located on the Wardensville Farm in the eastern part of the state, arrangements will be made to do so on June 26. Here is located a bluegrass pasture involving approximately 40 acres on which the response to fertilizers is being measured by grazing animals as well as by clipping the grass under both permanent and movable cages.

A DIGEST OF PASTURE RESEARCH LITERATURE

DR. A. J. Pieters, Principal Agronomist of the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, has compiled a digest of pasture research literature in the continental United States and Canada for the period of 1885 to 1935, and the Department is offering the digest in mimeographed form free of charge to all of those interested as long as a rather limited supply lasts.

In a foreword to the digest, P. V. Cardon states, "This digest is offered as a guide to research workers who are formulating research projects with pasture crops and with methods of establishing, maintaining, and utilizing pastures." While Dr. Pieters is credited with the final compilation of the digest and with all the notes and comments that accompany the 704 separate citations, others who have contributed to the enterprise include C. R. Enlow, who initiated the digest in 1933, and H. N. Vinall, M. Hein, and E. M. Coffman.

The digest is limited to pasture literature, hence no range literature is included. It relates chiefly to those parts of the United States and Canada which lie between the Atlantic Seaboard and the 97th meridian of longitude, although publications relating to the humid Pacific Coast region and to irrigated pastures in the West are also included. The material is arranged first by states followed by sections

dealing with publications of the U. S. Dept. of Agriculture, Canadian contributions, and a miscellaneous section. A comprehensive index adds materially to the value of the digest for reference purposes.

NEWS ITEMS

F. S. WILKINS, Research Assistant Professor of Agronomy at Iowa State College, died on March 31 at the age of 46. Since his appointment to the staff at Iowa State College in 1914, he had been in charge of forage crops investigations, and the results of his research have been published in a number of experiment station bulletins and journal articles.

DR. W. H. MACINTYRE, head of the Department of Chemistry, University of Tennessee and consulting chemist for the TVA, has been selected to receive the 1936 Charles Herty award for outstanding service in the field of chemistry in the South.

S. D. CONNER, Research Chemist in the Department of Agronomy, Indiana Agricultural Experiment Station, Lafayette, Ind., died last month following an appendicitis operation. Professor Conner had long been active in affairs of the Society and held three important committee assignments at the time of his death.

JOHN W. GILMORE, Professor of Agronomy, University of California, resident at Davis, is at present in Chile, having sailed with Mrs. Gilmore on February 7, to return some time in August. On the invitation of the Chilean Government, Professor Gilmore is instructing the young men who will teach and advise the prospective settlers on virgin lands in the Central Zone of Chile. The soil and climatic conditions of this region correspond closely to those found in California, between Colusa and Merced. This is the second time the Republic of Chile has called upon Professor Gilmore to help in the solution of her problems. Besides serving at Cornell, Pennsylvania State College, and California, he has, at various times also been instrumental in organizing agriculture and agricultural education in China, the Philippines, India, Hawaii, the Dominican Republic, and Mexico.

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APPARATUS FOR THE MEASUREMENT OF CO_2 EVOLVED DURING THE DECOMPOSITION OF ORGANIC MATTER IN SOILS[1]

B. N. SINGH AND P. B. MATHUR[2]

DETERMINATIONS of CO_2 produced during organic matter transformations in soils are generally made by absorption of CO_2 in baryta solution which is subsequently titrated against standard HCl. In the course of investigations on microbial activity as evidenced by evolution of CO_2 following additions of organic matter residues to the soil, the method of gas analysis was found to be convenient and an apparatus for this purpose has been constructed in this laboratory. Samples of moist soil were placed in 500-cc soil chambers and the CO_2 production determined by analyses of the gaseous mixtures by means of a Haldane absorption bulb.[3] The amount of CO_2 evolved per 100 grams of dry soil may be easily calculated if the percentage content of CO_2 in the gaseous mixture and the total amount of gas in the soil chamber are known. Analysis by means of a KOH bulb gives the percentage CO_2 content and the total volume of gas in the chamber is calculated in the following manner: The decrease in the pressure of the gas in the soil chamber following the withdrawal of a sample for analysis is noted and the volume of this test portion at the atmospheric pressure measured. From these data the desired total volume of gas x is easily computed by the formula $x = \frac{V.H}{h}$, where V = volume of the test portion withdrawn at the atmospheric pressure, H = atmospheric pressure in mm paraffin,[4] and h = decrease in pressure in mm paraffin in the soil chamber.

The KOH bulb (C) and the compensation pipette (B′) of the apparatus (Fig. 1) are of the type employed by Haldane. The 5-cc measuring pipette (B) is graduated into hundredths of a cc, the mer-

[1]Contribution from the Institute of Agricultural Research, Benares Hindu University, Benares, India. Received for publication January 25, 1936.

[2]Kapurthala Professor of Plant Physiology and Agricultural Botany and Assistant, respectively.

[3]HALDANE, J. S. Methods of Air Analysis. London. 1912.

[4]In determination of H, weight of 10 cc paraffin (in specific gravity bottle previously calibrated with mercury) = 7.88 gram; therefore, its density = 0.788 and H = 760 × 13.6/0.788 = 13,110 mm.

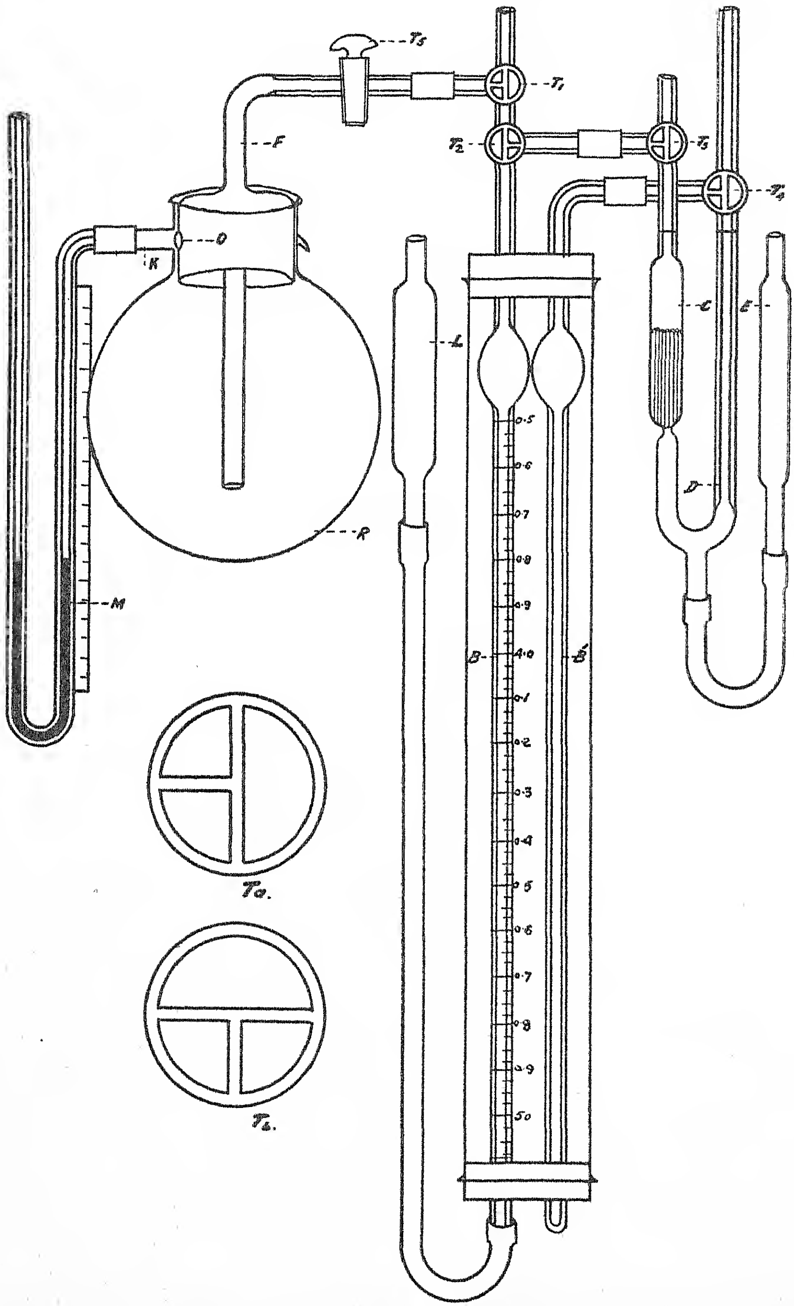

FIG. 1.—Apparatus for the determination of CO_2 production in soils

cury level adjustments being made by means of the bulb (L). The measuring pipette (B) and the compensation pipette (B′) are enclosed within a glass jacket the water in which is kept stirred in order to maintain a uniform temperature. The soil chamber (R) possesses a ground glass stopper to which is attached the tube (F), one extremity of which projects into the chamber while the other carries a tap (T_5). To the soil chamber is also attached a side-tube (K) with which is connected a manometer (M). By turning the ground glass stopper the soil chamber can be put in communication with the manometer through the orifice (O).

Samples of moist soil equivalent to 50 grams of dry soil which had been passed through a 2-mm sieve and thoroughly mixed were placed in the soil chambers. In all cases the moisture content in the soil was adjusted to 20 to 25% by the addition of distilled water. Dry CO_2-free air was allowed to enter the soil chambers which were then placed in a thermostat and incubated at 30 ± 0.1° C for several hours. After fixed intervals the soil chambers were removed from the thermostat and connected with the absorption apparatus and the manometer (M) as shown in Fig. 1. The manipulation is easy. Turning the tap T_2 in the position Ta, the KOH levels in the bulb (C) and the side-limb (D) are set by opening the taps (T_3 and T_4) and sliding the bulb (E) up or down, the taps (T_3 and T_4) being subsequently closed to the atmosphere. By means of the levelling bulb (L) the mercury in the pipette (B) is brought to the tap and the tap T_1 is turned in the position Tb. Now the tap T_5 is opened and the soil chamber rotated on its ground glass stopper so that it communicates with the manometer (M). The pressure indicated by the manometer is read and a portion of gas withdrawn into the pipette (B) by lowering the levelling bulb. The decrease in pressure in the chamber following the withdrawal of the gaseous sample is noted. Subsequent to this the tap T_5 is closed, the tap T_2 turned as shown in Fig. 1, and the volume of the gas withdrawn determined after setting the potash levels in C and D.

Knowing the decrease in pressure in the soil chamber and the volume occupied by the sample withdrawn at atmospheric pressure, the total amount of gas in the chamber is easily computed. The procedure for analysis of the mixture in order to determine the CO_2 content is as follows: The sample just withdrawn is freed from CO_2 so that all the capillaries of the apparatus may be filled with nitrogen and oxygen. Sampling is done by the washing method[5]. The gas samples are drawn in and sent out of the measuring pipette by means of the mercury levelling bulb, one or two washings usually being given. After the final washing is completed about 5 cc of the sample are taken into the pipette (B), the potash levels being set as before. The subsequent process consists in sending the gaseous sample back and forth several times into the KOH bulb. When the CO_2 has been completely absorbed the decrease in volume of the test sample is noted, after setting the potash levels in the usual fashion.

[5]CARPENTER, T. M. A comparison of methods for determining the respiratory exchange of man. Carnegie Inst. Pub. 1915.

The length of the intervals after which analyses are carried out is determined by the rate of CO_2 production from the soil. The organic matter decomposition in the soil being of the nature of oxidation, oxygen is absorbed and increasing amounts of CO_2 accumulate in the soil chamber. To know the limit beyond which concentrations of CO_2 will result in depressing the rate of evolution of CO_2, five series of experiments were performed. In each series the sub-samples for individual experiments were drawn from a single sample of soil. Each of the five samples of soil was passed through a 2-mm sieve and the moisture content adjusted to 20% in all of them. Various concentrations of CO_2, ranging from 0 to 11%, were allowed in the soil chambers and the total CO_2 production was determined after 12-hour periods. In each series 12 experiments were performed, each experiment being run in triplicate. The average amounts of CO_2 produced in the various experiments are shown separately in Fig. 2.

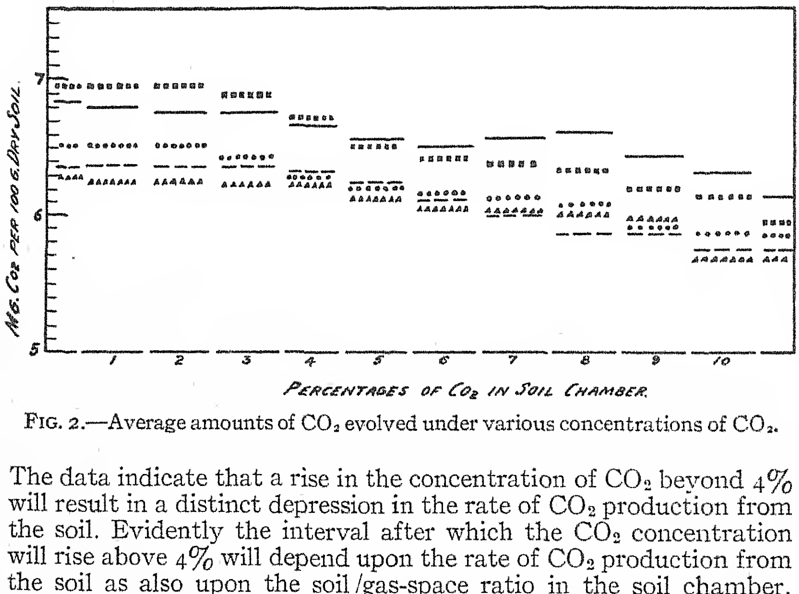

FIG. 2.—Average amounts of CO_2 evolved under various concentrations of CO_2.

The data indicate that a rise in the concentration of CO_2 beyond 4% will result in a distinct depression in the rate of CO_2 production from the soil. Evidently the interval after which the CO_2 concentration will rise above 4% will depend upon the rate of CO_2 production from the soil as also upon the soil/gas-space ratio in the soil chamber. With samples having a high rate of CO_2 production smaller amounts of soil should therefore be used.

CAPILLARY CONDUCTIVITY MEASUREMENTS IN PEAT SOILS[1]

L. A. RICHARDS AND B. D. WILSON[2]

DURING the summer of 1934 an apparatus was constructed for the purpose of measuring the capillary conduction of water in peat soils. The study was intended to include peats that had never been cultivated and those that had been tilled for different periods of time. Although it became necessary to discontinue the investigation before it was completed, the technic that was employed in the work and the results which were obtained appear to be of sufficient interest to justify the present report.

The readiness with which water is conducted in soil may be expressed in terms of a conductivity factor defined as the ratio of flow to water-moving force. In this paper flow is expressed as the number of cc of water which in 1 second cross an area of 1 square cm in the soil perpendicular to the flow. Water-moving force is expressed in dynes per gram. In a horizontal direction the water-moving force is equal to the pressure gradient in the soil water divided by the density of the water.

APPARATUS EMPLOYED AND EXPERIMENTAL PROCEDURE

The experimental procedure was similar to that described in a previous paper by one of the authors,[3] but improvements were made in the design and arrangement of the apparatus. Fig. 1 shows one of the capillary-conductivity units used in the present experiment. The column of soil to be studied was mounted in the telescoping brass cylinders A and A′ between two hollow porous cells B and B′ which were made especially for the purpose. The flow of water to and from the soil column took place through the large tubes C and C′. The water in the cells, and hence in the soil, was automatically maintained at a pressure less than atmospheric pressure. It is desirable to use atmospheric pressure as the zero pressure reference; thus the water may be said to have been under tension. Using the term tension or capillary tension for the negative pressure existing in water in an unsaturated soil avoids the necessity of dealing with a negative quantity. The difference in the tension in the soil water at the two ends of the soil column was measured by a differential manometer D which was connected through tubes E and E′ to small-bore porous tubes extending across the ends of the soil column. Manometer F connected to one of these tubes measured the tension in the soil water at one end of the column. The frame G, connected to a stranded cable passing over a pulley shown at the left of the figure, was used to subject the column of soil to a constant compression of 708,000 dynes per square cm. The initial length

[1]Contribution from the Departments of Physics and Agronomy, Cornell University, Ithaca, N. Y. Received for publication February 27, 1936.

[2]Formerly Instructor in Physics, Cornell University, now Research Assistant Professor of Soils, Iowa Agricultural Experiment Station; and Professor of Soil Technology, Cornell University, respectively. The authors wish to express their appreciation to Dr. R. C. Gibbs for making available the constant temperature room of the Department of Physics where this work was done.

[3]RICHARDS, L. A. Capillary conduction of liquids in porous mediums. Physics, 1:318. 1931.

of each soil column was 12.1 cm and in each case the decrease in length during the 4½ months of the experiment was less than 0.2 cm. The inside diameter of the brass tube containing the soil was 12.1 cm.

Fig. 2 shows the two capillary conductivity units, completely assembled, which were used in the investigation. Cloth wicks served to keep the air in the water-tight wooden chambers saturated with moisture in order to prevent the evaporation of water from the soil column. The flow of water to and from each soil column was read by means of burette tubes. A felt-padded wooden hammer, H, operating about 20 times a minute, served to agitate the mercury in the vacuum

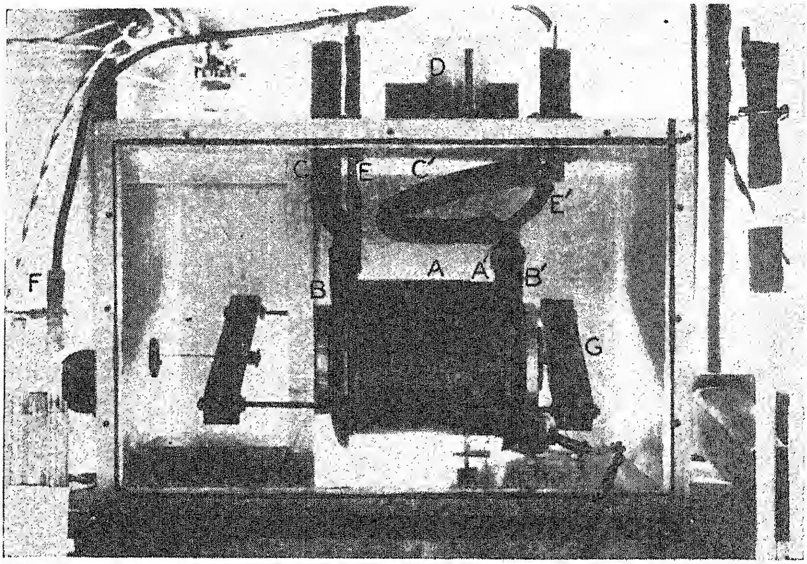

FIG. 1.—Apparatus used for measuring the capillary conductivity of water through soil.

pressure control manometers, I. These manometers, the principle of operation of which has been described elsewhere,[4] automatically maintained the water tension at various parts of the system within 0.5 mm of mercury of the desired values. A steady flow of water was assumed to obtain when the flow to and from the soil column differed by less than 1%. During the experiments the temperature of the room was held at 25° ± .05° C.

In calculating the capillary conductivity of the soil the following formula was used: $K = Q/t \times Ld/A \Delta p$, where K is the capillary conductivity, Q/t is the cc of water per second passing through the soil column, L is the length of the soil column in cm, A is the area of the soil column in square cm, d is the density of water in grams per cc, and Δp is the difference in pressure (difference in tension) of the water at the two ends of the column expressed in dynes per square cm.

[4]RICHARDS, L. A. Low vacuum pressure control apparatus. Rev. Sci. Instruments, 2:49. 1931.

SOILS USED

Two peat soils were used in the experiments. One of the soils was collected from the surface zone of a virgin deposit of granular, well-decomposed woody peat. The other soil was taken from the plowed layer of an adjacent area that

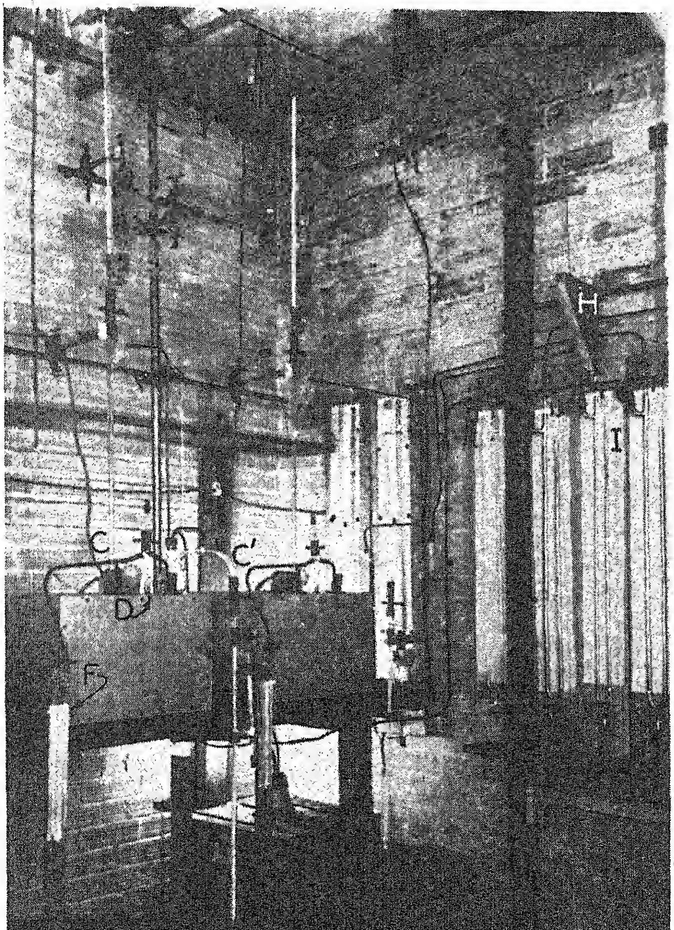

FIG. 2.—Two capillary conductivity units showing the arrangements used for controlling and measuring the flow of water through the soil column.

had been cultivated annually for a period of about 50 years. The structure of the soil had been greatly modified owing to cultural operations and the sample was composed largely of finely divided material. The samples of soil were collected in June, 1934, and placed immediately in air-tight containers to prevent loss of moisture.

On September 1 each of the soils was transferred to one of the telescoping cylinder units of the apparatus. In filling the cylinder with the virgin peat, an attempt was made not to destroy the structure of the material. The finer particles were worked in and around the larger lumps so that large voids would not exist in the soil column.

RESULTS OF THE EXPERIMENT

The data of Table 1 show the capillary conductivity of the soils during the course of the experiment at different capillary tension values. Capillary tension is expressed as the number of cm of water column necessary to produce the tension. The results of the work, which should be regarded as preliminary only, reveal an important property of peat soils. It may be seen in the table that an equilibrium flow was first attained with the virgin soil.

TABLE 1.—*The capillary conductivity of water in peat soils at different capillary tension values.*

Date of record	Capillary tension, equivalent water column in cm	Capillary conductivity, seconds $\times 10^{11}$
	Virgin Peat	
Oct. 1	22.8	614.0
Nov. 8	193.7	0.0
Dec. 20	9.5	2,243.0
	Cultivated Peat	
Oct. 23	21.9	2,810.0
Dec. 20	73.3	20.7*
Feb. 8	71.4	12.8*

*Since steady flow was not attained, the average of the inflow and outflow was used in calculating these conductivity values.

After making the conductivity calculation recorded for October 1, the capillary tension was set at 193.7 cm of water. This setting revealed the rather surprising fact that even at the relatively high moisture content of the soil[5], the water seemed not to be present in a continuous liquid phase because flow through the column ceased. The tension was then reduced to 9.5 cm of water, and as was expected, the conductivity increased to a relatively high value.

The relation of tension to conductivity cut-off in the case of the soil that had been cultivated was similar to that of the virgin soil. It may be seen in the table that increasing the tension from 21.9 to 73.3 cm of water reduced the conductivity to less than 1% of its previous value. The value of K calculated on December 20 was not an equilibrium value because the inflow of water to the column exceeded the outflow by more than 1%. Nine weeks later, on February 8, an equilibrium flow had not been attained. During that time the excess of inflow over outflow caused an accumulation of water in

[5]Determinations of the moisture content of the soils at different capillary tensions were not made, but the moisture content corresponding to a water column of 193.7 cm would probably be of the order of 80 to 100% on the basis of dry soil.

the soil column, yet the conductivity continued to decrease. Because equilibrium was approached from the wet side the findings seem to indicate that mobile water from the capillary stream was converted to an immobile or bound phase. Further investigation is necessary in order to explain the observed phenomenon in terms of fundamental processes. An explanation may be found in the replacement of adsorbed or occluded air in the organic colloid-water system by water.

The capillary tension at which the conductivity becomes zero is of practical significance in that it makes known the maximum height to which water can rise by capillary action in a moist soil. Because of the discontinuance of the investigation the capillary tension for conductivity cut-off was not accurately determined for either of the soils. It seems certain, however, that the cutoff would occur at much lower tension values than those which have been found for mineral soils ranging from coarse sand to fine clay.[6]

Zero conductivity occurring at low tensions seems to explain why certain crops growing on peat soils containing relatively high percentages of moisture suffer from drought. When the conductivity is zero and the moisture adjacent to the roots of plants has been exhausted, the plants will suffer drought unless the roots grow out to a new moisture supply.

SUMMARY

An apparatus of improved design was used in measuring the capillary conductivity of water in peat soils. A description of the apparatus is given.

At low tensions the soils were found to possess capillary conductivities greater than those that have been reported for mineral soils. However, the capillary conductivity was found to become zero at lower tensions in the two peat soils studied than has been reported for mineral soils.

Difficulty was experienced in measuring the capillary conductivity of peat soils because of the length of time required for the moisture content of the soils to reach an equilibrium value at a given capillary tension.

[6]See footnote 3.

TOXICITY FROM ARSENIC COMPOUNDS TO RICE ON FLOODED SOILS[1]

J. FIELDING REED AND M. B. STURGIS[2]

DURING recent years, farmers in the rice area in southwest Louisiana have experienced considerable difficulty in the growing of rice when it follows cotton which has been dusted with calcium arsenate for boll weevil control. This difficulty is largely confined to the rice area where the soil is flooded for about 3 months during the growing season of rice. The investigations presented here concern observations on arsenic toxicity in certain soils of this rice area.

Arsenic toxicity in soils is no new problem. Large amounts of arsenic are used annually in the spraying of fruit and, in the South particularly, in the dusting of cotton. The greater part of this arsenic finds its way to the soil and the question has been raised as to what toxic effect these accumulations may have on succeeding crops. Headden (6, 7, 8)[3], working at the Colorado Agricultural Experiment Station on the arsenical poisoning of fruit trees over a period of 20 years, found that in the order of time, the use of arsenic as a spray was accountable for the death of a large number of trees. A considerable amount of work on arsenic poisoning has been carried out at the South Carolina Experiment Station (2). It was found that applications of calcium arsenate in cotton boll weevil control had affected the productivity of certain soil types. The coarse-textured gray soils were seriously affected by relatively light applications of calcium arsenate, whereas the fine-textured, dark-colored soils were not seriously affected by applications which would be commonly used in combating the cotton boll weevil.

Further investigations in South Carolina (1) showed that the total amount of arsenic present in a field soil was not necessarily related to the toxicity toward crops. The concentration of soluble arsenic in soils, as measured by collodion bag dialysates, was usually a more reliable index of arsenic toxicity than was the total arsenic present in the soil. Greaves (5) at Utah made a number of determinations of arsenic in various forms, though with no yield correlations, and concluded that the toxicity of arsenic to plants and soil microorganisms is governed by the water soluble soil arsenic.

Still further work the following year at South Carolina (3) indicated that there was a definite relationship between the amount of reactive iron present in the soil and the arsenic toxicity. The gray, light soils, low in reactive iron, were very sensitive to additions of calcium arsenate, whereas the dark, heavy soils, relatively high in reactive iron, were not seriously affected by large amounts of calcium arsenate. In fact, it was shown that additions of ferrous sulfate to soils in

[1]Contribution from the Department of Agronomy, Louisiana Agricultural Experiment Station, Baton Rouge, La. Published with the approval of the Director of the Louisiana Agricultural Experiment Station. Received for publication March 23, 1936.

[2]Assistant in Agronomy and Research Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 436.

which arsenic toxicity had developed benefitted subsequent crop growth, this benefit being due probably to absorption of arsenates by iron hydroxide.

No particular difficulty has been experienced in Louisiana when cotton is treated with calcium arsenate and followed by another crop of cotton or by some other upland crop. Either the applications have not been heavy enough to cause toxicity or the soils have such chemical and physical properties that the arsenic does not exert any effect. On the other hand, as mentioned above, a number of farmers have reported trouble with rice when it follows cotton which has been dusted with calcium arsenate. The rice either gave very low yields or blighted completely. The yield and quality of the straw were not harmfully affected, but the rice heads were empty and unfit for milling.

EXPERIMENTAL

For this study of arsenic toxicity, samples of soils from three different places in the rice area in southwest Louisiana were secured, *viz.*, a Crowley silty clay loam from the Rice Experiment Station at Crowley, Louisiana, and two soils from farms reporting trouble, a Crowley very fine sandy loam, and a Lake Charles clay. Three-gallon pots were filled with these soils and varying amounts of arsenic added to the soils. These pots were planted to rice and determinations made of the total arsenic, water-soluble arsenic, and 0.05N HCl-soluble arsenic in the soil while the rice was flooded and at the conclusion of the test. The rice was cut when mature, the yields computed, and total arsenic determined in the heads and straw separately. Total arsenic in the soil was determined by the method suggested by Greaves (4), modified to use the Gutzeit test as recommended by the A. O. A. C. (10) instead of the Marsh test. The water-soluble and 0.05N HCl-soluble arsenic were determined by the Gutzeit test in aliquots of extracts of 1:10 ratio of soil to extractant. For the arsenic in the rice heads and straw, the method of the A. O. A. C. for arsenic in plants was followed.

DISCUSSION OF RESULTS

It may be seen from Table 1 that with rice arsenic toxicity apparently is dependent upon soil type just as has been found in the case of cotton. No appreciable effect was noticed on the Crowley silty clay loam with arsenic applications up to 150 pounds per acre, while in the case of the Crowley very fine sandy loam, the rice was very noticeably affected by applications of 50 pounds or more per acre. Such applications have not proved toxic to cotton on these soils. Evidently in the presence of the highly reducing conditions which are prevalent throughout the growing season of rice, the arsenates are reduced to the much more toxic arsenites and possibly even to gaseous arsine. This latter condition is evidenced by the fact that there is a decrease in the arsenic content of the soil through the growing season.

The exact extent of the reducing condition that prevails in the soil when it is planted to rice and kept continuously flooded was measured by determining the oxidation-reduction potential of soil samples in pots during the growing season of rice. The Eh, or oxidation-reduction potential, dropped from Eh 0.67 to Eh 0.19 during the submergence. Other tests conducted previously with the Crowley silty clay loam

TABLE 1.—*Effect of calcium arsenate on yields of rice in certain soils.*

Treatment, lbs. per acre	Soil type	Average yield of of straw, grams	Average yield of of head, grams	Head yield gain or loss %
1, No treatment	Crowley silty clay loam	9.0	4.7	0.0
2, 16 lbs. calcium arsenate	Crowley silty clay loam	9.7	6.8	+45.0
3, 50 lbs. calcium arsenate	Crowley silty clay loam	9.0	4.5	—4.2
4, 150 lbs. calcium arsenate	Crowley silty clay loam	9.0	5.5	+17.0
5, No treatment	Crowley very fine sandy loam	37.0	11.0	0.0
6, 50 lbs. calcium arsenate	Crowley very fine sandy loam	35.6	6.0	—45.0
7, 150 lbs. calcium arsenate	Crowley very fine sandy loam	35.2	4.0	—64.0
8, 300 lbs. calcium arsenate*	Lake Charles clay loam	No yield, rice unharvested		

*No pot test was run on this soil. 300 lbs. of calcium arsenate per acre had been used by the farmer and the rice blighted completely.

soil showed that the reduction of sulfates to sulfides took place at a potential of Eh 0.38 or higher. Since sulfate to sulfide reduction is listed in the standard tables as occurring at a lower oxidation potential than arsenate to arsenite reduction, there is every reason from this standpoint to expect reduction of arsenate at least to arsenite.

Most investigators maintain that water-soluble arsenic is an index of arsenic toxicity in soils. It may be seen from Table 2 that no water-soluble arsenic or a very small trace was found in any case, but a close relationship was observed between the 0.05 N HCl-soluble arsenic and toxicity. The amount of dilute acid-soluble arsenic may better represent the arsenic which can affect the plant than does the amount of water-soluble arsenic. In the case of the Crowley very fine sandy loam where toxicity was particularly noticeable with the 50-pound per acre application, the amount of arsenic soluble in 0.05 N

TABLE 2.—*Total arsenic, water-soluble arsenic, and 0.05 N HCl-soluble arsenic in treated rice soils at the conclusion of the test.*

Treatment No.	Total arsenic in soil, p.p.m.	Water-soluble arsenic, p.p.m.	0.05N HCl-soluble, p.p.m.	Arsenic in heads, p.p.m.	Arsenic in straw, p.p.m.
1	2.0	0.0	0.0	0.4	0.3
2	3.0	0.0	0.5	0.5	0.5
3	4.0	0.0	1.0	1.0	0.5
4	6.0	0.0	1.0	1.7	0.7
5	5.0	0.5	0.5	0.8	0.6
6	10.0	0.5	3.5	2.7	1.2
7	20.0	1.0	6.0	5.0	2.5
8	20.0	0.5	4.5	—	—

HCl was three times as great as the amount of acid soluble arsenic in the Crowley silty clay loam which had received an application of 150 pounds per acre.

Some interesting observations were made in connection with the amounts of arsenic put into the soil and their relation to the amounts found during the test and at the conclusion of the test (Table 3). There was a decided decrease in the amount of total arsenic found at the conclusion of the test as compared with the amount at the beginning, in every case, except in the untreated pots. The arsenic content remained practically constant in the untreated pots, while in the treated pots the content tended to drop to the level of the untreated soil, though in no case did it fully fall to this level. The difference between the sum of the amount of arsenic added and the arsenic present in the untreated soil and the sum of the amount of arsenic determined in the soil and in the rice after the rice was harvested is listed in Table 3 as arsenic "unaccounted for." By reference to the amounts of arsenic found in the stalks and heads of the rice crop, it may be seen that a relatively small amount of the total arsenic is removed through the crop. Under the highly reducing conditions prevalent when rice is being grown in a flooded soil, the answer to the question of what happens to this "unaccounted for" arsenic which had been applied as an arsenate might be found in the reduction of a good portion of the arsenates to arsine. This reduction appears to proceed until a certain level of arsenic content is reached, that level being the amount of arsenic occurring in the untreated soil.

TABLE 3.—*Summation of arsenic determinations of pot tests of rice in treated soils.*

Treatment No.	Arsenic added to soil May 31*	Arsenic in soil Aug. 10	Arsenic in soil after harvest	Arsenic in rice heads	Arsenic in rice straw	Arsenic "unaccounted for"
1	0.00	20.00	20.00	0.002	0.002	0.0
2	36.00	40.00	30.00	0.004	0.004	26.0
3	113.00	100.00	40.00	0.004	0.004	93.0
4	338.00	200.00	60.00	0.008	0.005	298.0
5	0.00	80.00	50.00	0.008	0.021	—
6	113.00	150.00	100.00	0.016	0.042	93.0
7	338.00	350.00	200.00	0.020	0.070	218.0

*All results expressed as total Mg of As_2O_3 in soil or rice.

Many cases of the microbiological reduction of arsenical compounds to arsine have been reported, but, in so far as the authors could determine, no special study has been made of the reduction of arsenates to arsine in soil under submerged conditions. Thom and Raper (9) have studied arsenic decomposing fungi in the soil, and have shown that arsenic accumulation in the soil would not ordinarily be expected to occur, since arsenical substances carried to the soil come in contact with decomposing agents which tend to break them into volatile forms. Even if this loss of arsenic were to proceed as suggested, it would take a number of years to remove enough arsenic through this means to make the soil suitable for rice again. In the

cases studied, toxicity had been experienced on the farms for a number of years in succession with rice, though to a diminishing extent. No trouble was had when another upland crop, such as corn or cotton, was planted in place of rice. This would seem to indicate rather conclusively that it is the reduced arsenic compounds, arsenites, etc., which are particularly toxic to rice under flooded conditions.

SUMMARY

Arsenicals used in the dusting of cotton have had a toxic effect on succeeding crops of irrigated rice in certain soils of the Southwest.

The effect on the yield of rice of applications of varying amounts of calcium arsenate on different soil types was studied and it was found that the toxic effect was governed largely by the soil type. Rice on the lighter soils was seriously affected by applications of 50 pounds per acre of calcium arsenate, while on the heavier soils 150 pounds per acre were not injurious. No correlation could be found between water-soluble arsenic and toxicity, though a relationship existed between 0.05N HCl-soluble arsenic and toxicity.

Less total arsenic was found in the soil at the conclusion of the test than was present at the beginning. An analysis of the rice heads and straw showed that the loss could not be accounted for by crop removal. The soil was found to be in a highly reducing condition when flooded under cultivation, and it is suggested that this loss in arsenic content might be accounted for by complete reduction to gaseous arsine. Furthermore, the evidence seems to indicate rather conclusively that it is the reduced arsenic compounds, arsenites, etc., that are particularly toxic to rice under flooded conditions.

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EFFECTIVENESS OF FURFURAL PETROLEUM COMBINATIONS IN ERADICATING CERTAIN NOXIOUS WEEDS[1]

H. L. BUCKARDT[2]

THE national loss caused by weeds has been estimated to amount to $3,000,000,000 annually (1).[3] This loss is 12 times the estimated loss from animal diseases, 1⅔ times the annual loss caused by plant diseases, and 3 times the estimated annual loss from insect pests of plants.

Many methods to reduce loss caused by weeds have been utilized by different workers. Among these methods, chemicals have been used with varying degrees of success.

The purpose of this study was to test several furfural-petroleum combinations to determine (a) the effectiveness of the various materials in killing certain weeds, (b) the most effective rate of application, (c) the influence of climatic conditions and time of day on the effectiveness of application, and (d) the rapidity of kill resulting from the application of different chemicals.

METHODS AND MATERIALS

Two general methods were used in applying the furfural-petroleum combinations, *viz.*, individual plant application and broadcasting.

The individual plant treatment method was used in trials on dandelion (*Taraxacum officinale*), broad-leaved plantain (*Plantago major*), and buckhorn (*Plantago lanceolata*) (2). This method consisted of making an application of the chemical on the crown of the plant by the use of a "cane." The cane was a hollow cylindrical tube, 40 inches long, containing an automatic operating device in one end and a cap to permit pouring in of the chemical on the other end. The operating device was so constructed that each stroke of the cane caused the valve to permit an equal quantity of material to flow on the plant.

The broadcast method was used in trials on quack grass (*Agropyron repens*) and field bindweed (*Convolvulus arvensis*). This method consisted of spraying the chemical uniformly over the area to be treated by means of a nozzle hand sprayer.

Following is a list of the furfural-petroleum combinations used in the tests, including both the laboratory number and a statement as to the composition of each:

1847—Stanolex Fuel Oil No. 1 (viscosity of 32 seconds).

1856—Stanolex Fuel Oil No. 1 98% plus 2% hard stanolite.

1849—Stanolex Fuel Oil No. 1 95% plus 5% furfural.

1850—Stanolex Fuel Oil No. 1 77% plus 10% furfural, plus 13% mutual solvent.

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[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill., resulting from a cooperative research project between the University of Illinois and the Standard Oil Company of Indiana. Received for publication March 5, 1936.

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[3]Figures in parenthesis refer to "Literature Cited," p. 442.

1852—Stanolex Fuel Oil No. 3 (viscosity of 37 seconds).
1853—Stanolex Fuel Oil No. 3 90% plus 10% furfural.
1905—Stanolex Fuel Oil No. 3 85% plus 15% furfural.
1854—Road Oil No. 3 (viscosity of 480 seconds).
1855—Road Oil No. 3 95% plus 5% furfural.
1895—Sodium arsenate and sodium silicate solution 20%.

CLIMATE

During the period of the experiment wide differences occurred in the amount of precipitation and extremes of temperature. Since these factors of the environment influenced the effectiveness of the weed killers, a brief summary of these important ecologic factors is given in Table 1.

TABLE 1.—*Semi-monthly rainfall in inches and maximum, minimum, and mean temperatures in °F for July, August, September, and October, 1932.*

	July 1–15	July 16–31	Aug. 1–15	Aug. 16–31	Sept. 1–15	Sept. 16–30	Oct. 1–15	Oct. 16–31	Total
Rainfall, in...	1.58	0.83	2.45	0.18	1.95	1.68	1.28	2.56	12.51
Max. temp., °F........	98.0°	98.0°	89.0°	95.0°	89.0°	82.0°	80.0°	77.0°	—
Min. temp., °F........	52.0°	55.0°	59.0°	51.0°	47.0°	43.0°	31.0°	28.0°	—
Mean temp., °F........	72.8°	81.4°	74.5°	76.6°	70.7°	62.4°	54.5°	52.7°	—

The highest temperature during this 4-month period was 98° F, which is 7° less than the highest temperature recorded at Urbana since 1894. The mean temperature for this period was slightly higher than normal. The rainfall was below normal for July and August but above normal for September and October.

RESULTS AND DISCUSSION

After treatment, observations were made at weekly intervals to determine the effects of the chemicals applied. Frequently, it was found that only the top growth was killed for plants that appeared to be dead above ground after a period of time sent up new growth and continued living. Hence, for a complete record of the results, it was necessary to make final counts several weeks after treatment.

PLANT APPLICATION METHOD

Lawn weeds.—Data are given in Table 2 showing the results of treatments made by the plant application method for three kinds

TABLE 2.—*Percentage of dandelion, buckhorn, and broad-leaved plantain plants killed after applying 4 cc of various chemicals.*

Kind of plant	Number of chemical applied*									
	1847	1856	1849	1850	1852	1853	1905	1854	1855	1895
Dandelion.......	64.7	65.5	69.3	58.3	61.9	63.1	—	52.9	47.6	—
Buckhorn.......	94.1	—	—	72.3	75.0	—	100.0	—	—	81.2
Broad-leaved plantain.......	100.0	100.0	100.0	100.0	100.0	100.0	100.0	50.0	50.0	95.0

*See list of chemicals, page 437.

of weeds, namely, dandelion, buckhorn, and broad-leaved plantain. The number of weeds ranged from 100 to 750 plants per 100 square feet. All results were obtained by making plant counts.

The data in Table 2 indicate that the heavier oils, represented by Nos. 1854 and 1855, were less toxic than the lighter oils represented by the other numbers; that the oils with furfural added were slightly more toxic; and that dandelion plants were more resistant to treatment than buckhorn and broad-leaved plantain.

Tests with these different materials during the season indicated that a larger percentage of the plants were killed during late June and July when the temperature was high and the soil moisture low than by similar applications made during August and September when there was more moisture and the temperature was lower. No difference was observed in the number of plants killed on different plats treated at different times during the day.

Greenhouse tests.—In order to study under controlled conditions the effect of different amounts of material applied, several series of the various species of lawn weed plants were transplanted into jars, placed in a greenhouse, and treated. Treatment consisted of different chemicals and different amounts of each chemical.

Results indicated that the amount of material necessary to kill any plant varied greatly with the size of the plant (4). Large dandelion plants, with roots 18 inches long, required over 3 times more material of the same strength to kill them than did seedling plants.

Further tests were made in order to study the rapidity of kill of the different materials. For this purpose dandelion plants with a leaf spread of approximately 4 inches in diameter were transplanted into jars and placed in a greenhouse where they were allowed to grow for 3 weeks and then treated (Fig. 1).

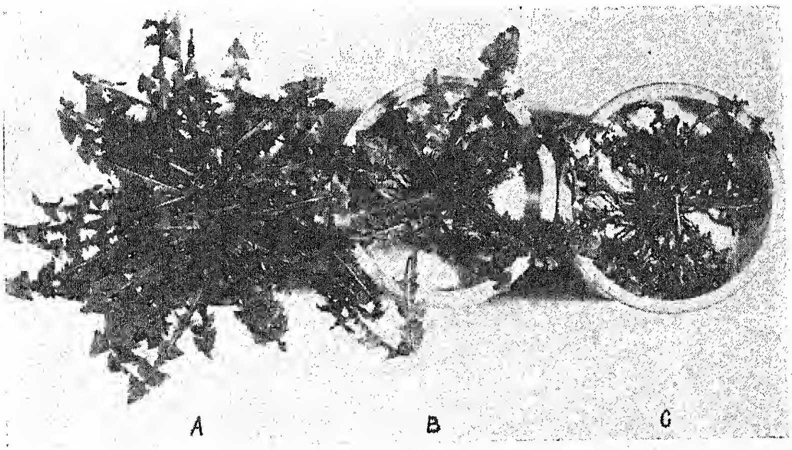

FIG. 1.—Three mature dandelion plants which were the same size before treatment. A, no treatment; B, 12 days after treatment with 1 cc of Stanolex Fuel Oil No. 3 plus 15% furfural; and C, same as B except 8 cc were used instead of 1 cc.

The data in Table 3 indicate that when furfural is added to the petroleum oils they become more rapid weed killers (5). Preliminary tests indicated that heavy oils represented by formulas Nos. 1853 and 1854 were slower to kill the plants than were the lighter oils represented by formulas Nos. 1847 and 1852, even when no furfural was added.

TABLE 3.—*Percentage of plants killed after different intervals of time following treatment with 2 cc of various chemicals.*

Chemical	Days after treatment		
	Two	Five	Seven
Fuel Oil No. 1 (No. 1847)	33	50	66
Fuel Oil No. 1 plus 10% furfural (No. 1850)	66	Dead	Dead
Fuel Oil No. 3 plus 15% furfural (No. 1905)	Dead	Dead	Dead

BROADCAST METHOD (3)

Results are reported on two kinds of field weeds treated by the broadcast method, namely, quack grass and field bindweed. Plats were established in areas where a dense growth of the species of weed to be treated was the only kind of vegetation present. Before treatment practically all plants were alive and the above ground growth was green. In this condition the plats were estimated to contain 100% living plants. Following treatment, the amount of injury was determined by estimating the percentage of the plat area which contained brown-colored, injured, and dead-appearing plants. The figure obtained was used to designate the percentage of top growth dead as a result of the treatment. The term "top growth dead" is used because the chemicals did not kill the roots of the plants. Consequently, after an interval of time following treatment, new growth replaced the dead top growth and the area again contained a dense green covering of the species of weed.

The data in Table 4 indicate that applications of 500 and 750 gallons per acre of the lighter oils were sufficient to kill most of the above ground growth of quack grass and field bindweed. Applications of 250 gallons per acre were less effective. The apparent injury from the treatments was in all cases reduced by new growth at the end of 6 weeks time. Observations made on the treated plats the following season indicated that there was very little, if any, difference between treated and control plats. The heavier oils, represented in Table 4 by Nos. 1854 and 1855, were not so effective in killing top growth as were the other materials.

A number of the plats for which data are given in Table 4 were retreated later in the season (October 14) with the same amounts of the same materials as were used in the first treatment. A sufficient number of plants survived this second treatment to produce a new heavy growth of weeds when observed 1 year later.

TABLE 4.—*Percentage of top growth dead at intervals after applying varied amounts of different furfural-petroleum materials on July 19, 1932.*

Treatment No.	Gallons per acre	Date observed and weed treated					
		August 1		August 18		October 7	
		Quack grass	Bind-weed	Quack grass	Bind-weed	Quack grass	Bind-weed
1847	250	90	100	60	15	30	0
	500	90	100	80	20	65	0
	750	90	100	100	30	90	0
1849	250	70	100	50	10	10	0
	500	85	100	85	10	50	0
	750	90	100	90	30	80	0
1850	250	70	100	50	15	10	0
	500	90	100	85	20	55	0
	750	100	100	100	30	80	0
1852	250	80	100	75	40	10	0
	500	90	100	80	55	45	20
	750	90	100	90	75	75	20
1853	250	75	100	70	35	20	10
	500	100	100	90	55	60	20
	750	100	100	95	70	90	25
1854	250	50	40	30	30	40	0
	500	70	50	60	40	40	0
	750	80	70	80	70	50	0
1855	250	50	50	30	20	5	0
	500	75	65	65	40	35	0
	750	85	90	85	65	60	0
1856	250	70	100	50	10	10	0
	500	90	100	80	25	35	0
	750	100	100	95	30	80	0

SUMMARY

Approximately 70% of the dandelion plants growing on plats where the grass was kept cut short were killed by one application of 4 cc of the best furfural-petroleum materials. Observations indicated that large mature plants required more material to kill them than did small plants. Some plants killed 3 inches below the crown produced new growth which appeared above ground 42 days following treatment.

A 100% kill was obtained when broad-leaved plantain plants were treated with 4 cc of the best materials.

A 100% kill was obtained with buckhorn plants treated with 4 cc per plant of the best materials. Smaller amounts were less effective.

One application of 250, 500, or 750 gallons per acre of any of the materials did not kill all the roots of either quack grass or field bindweed. A second application on the same plats with the same quantity as applied the first time did not give complete eradication.

Late June and July treatments gave a higher percentage of kill than late August and September treatments. Here, moisture was one of the most important factors involved.

No relationship was found to exist between the time of day when application was made and the resulting percentage of kill.

When added to petroleum oils, furfural increased their toxicity, causing them to kill with greater rapidity.

The lighter grade petroleum oils were in all cases more toxic than heavier grade oils.

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SHALL CROPS BE ADAPTED TO SOILS OR SOILS TO CROPS?[1]

E. N. Fergus[2]

ALL efforts to obtain profitable production in farm crops involve either improving the adaptation of crops to environment or improving environment for the crop. Probably most farmers practice mainly one or the other, but few follow one to the exclusion of the other. There are many ways in which farm crops can be adapted to environment, as, for example, by varietal improvement, choice of seed, seeding practices, choice of crop to suit soil type, etc., but none is more generally followed nor more potent for good or evil to civilization than selection of crops to suit the soil's productive capacity. Environmental adaptation, likewise, is brought about in several ways; for example, by cultivation, drainage, irrigation, manuring, liming, and applying commercial fertilizers. Undoubtedly, the practices of the latter group that most affect the well-being of society over a long period are manuring, liming, and fertilizing.

To the farmer on a highly productive and relatively inexhaustible soil, the difference between farm practices based upon adapting soil to crop, on the one hand, and those based upon adapting crop to soil, on the other, is likely to be largely academic. But to society the difference is critical because any soil farmed for several generations according to one of these practices will ultimately differ widely in productivity from a similar soil on which the other method of farming has been practiced. Most, if not all, countries of northern Europe practice an agriculture based upon soil adaptation, whereas large sections of China and India may be considered to have emphasized crop adaptation as their basic agricultural practice even though they have endeavored to conserve the mineral resources of their soils.

The advantages of a system of crop production based upon principles of building soil productivity to suit crops are familiar to all agronomists and therefore need not be discussed. Probably all agronomists are more or less aware, also, that the practice of selecting crops adapted to successive degrees of soil depletion will eventually exhaust the soil and bring agriculture to ruin, but as a group we have said little about it. Had we been greatly concerned about the outcome of the practice, perhaps there would be much less need for the present effort at rehabilitation and resettlement. Instead of hailing the "poor-land clover" and the "poor man's alfalfa," we should point out the danger such adaptations imply.

The phenomenal rise of the annual lespedezas to a prominent place among the crops of a large area of the United States has crystallized rather than introduced the problem of the final result of a system

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of farming based on selecting crops to suit a soil's decreasing fertility. It seems unlikely that anyone familiar with the history of the expansion of the lespedeza acreage will deny that the lespedezas have become so extensively grown largely because they are adapted to depleted soils, rather than because of their several quite desirable qualities, such as ease and economy of establishing stands, heavy yields of forage and seed, drought resistance, etc. Unwittingly, therefore, most farmers are actually impoverishing their land still farther after it has become too poor for other crops.

The outcome of this practice of choosing poor-land crops to suit a soil as it becomes impoverished, unattended by liming, manuring, and fertilizing, is certain to have serious consequences. For example, red clover once regularly produced excellent crops on land in Kentucky on which even adapted varieties will not now grow without lime and phosphorus. Instead of applying these materials to the soil, farmers use crops adapted to poorer soil. Redtop, orchard grass, and especially lespedeza are used. They require less calcium and phosphorus than clover, and lespedeza, at least, also seems able to obtain appreciable amounts unavailable to clover and other crops. Consequently, it seems that sooner or later the supplies of calcium, phosphorus, and other essential elements must become so much reduced that they are no longer sufficient even for lespedeza. There are areas in which this condition apparently has been reached already.

Again, poor-land crops, when grown on poor soil, yield crops of low quality. They are frequently very weedy, especially the forage crops. No crop so far discovered has quite equaled certain weeds in adaptability to poor soil. But more serious is the low quality of the crop itself. It reflects the poverty of the soil on which it grew. For example, the phosphorus content of lespedeza hay produced on poor soil in Kentucky varies from 0.1 to 0.17%, whereas all-legume hay produced on our best soils contains from 0.22 to 0.4%.[3] The protein content of the hay is in general proportional to the phosphorus content, which agrees with Orr's (8)[4] observation that forage deficient in minerals usually is also low in protein.

The significance of the low nutrient content of the poor-land crops becomes apparent when the many reported instances of malnutrition of animals that have been traced to mineral-deficient forage are considered. Most of these have been reviewed by Orr, and all are pertinent to the question of the nutritional value of poor-land crops, but especial significance is found in the results of studies of malnutrition of native cattle on native ranges in Florida (1, 2).

It will be recalled that two types of malnutrition were found in the slow-growing native herds, one caused by a deficiency of calcium in the forage, the other by a deficiency of phosphorus. The actual difference between the composition of the herbage on the affected and the healthy ranges was small; for example, the phosphorus content was, respectively, 0.082 and 0.133%.

These results possess even more meaning if considered along with such malnutrition studies as those made in Wisconsin (4) and in

[3]From analyses made by Department of Feed Control.
[4]Figures in parenthesis refer to "Literature Cited," p. 446.

Minnesota (3), which show that livestock in those states received insufficient amounts of phosphorus from crops containing from 0.09 to 0.19%. These grades of stock apparently required at least 0.3% in contrast to the 0.13% required by the native cattle of Florida. The Minnesota report expresses the opinion that the optimum phosphorus content of rations for cattle is about 0.4% on a dry-matter basis.

Grades of livestock, therefore, vary in their mineral requirements; poor grades being able to obtain their needs from herbages of low content, whereas high grades require feeds of high content. The known variation in minimum phosphorus requirement in forage, for example, is from 0.13 to 0.3%. Perhaps there are types of animals that can grow and be healthy on less than the lower figure, and it is more likely that some highly developed kinds require more than the higher figure. Most livestock in the United States is more or less improved and therefore has an intermediate minimum requirement. It is likely that most of this stock requires at least 0.2% of phosphorus which is 0.03% higher than the richest in phosphorus of the previously mentioned lespedeza hays grown on the poorer soils of Kentucky. A grade of livestock that obtains an insufficient amount of a mineral in its feed must evolve into a poorer grade unless the deficiency is corrected by some form of supplementary feeding. Undoubtedly, all agronomists will agree that it is better to increase the mineral content of the forage and other feeds by soil improvement.

The low nutritive value of poor-land crops grown on poor soil has a still more serious aspect, however. The human being is just as much dependent upon his food for minerals as the lower animals. Therefore, it is to be suspected that mineral malnutrition must likewise occur in peoples dependent upon food grown upon impoverished soil for their sustenance. While information pertaining to human malnutrition that may be ascribed to this cause is meager, there is enough to indicate that it exists in serious proportions. According to Maxwell (6), osteomalacia is common in women living in northern China and Manchuria. Many of the cases are caused by a deficiency of calcium in the native food plants (7), i. e., crops adapted to soils that are now deficient in minerals because of the long practice of a system of farming that has not provided for the return of minerals to the soil in amounts equal to those removed in crops (5). The manifestations of the disease were identical with those of the same disease in the native cattle of Florida, namely, as a skeletel breakdown most common in females that had borne offspring.

It seems highly improbable that such a disease could develop in humans in this country, outside of isolated areas, because much of our food is obtained from widely separated regions, some of which have soil of satisfactory mineral content. Nevertheless, the readiness and even enthusiasm with which our American farmers have received poor-land crops, together with their rather general indifference toward soil building and conservation, fill all but the least imaginative with some feeling of apprehension for the future.

In conclusion, it should be emphasized that while a system of farming based principally upon growing poor-land crops appears

wholly unsound as a permanent agricultural practice, it must not be assumed that its limited utilization is to be condemned. There are large areas of eroded and worn-out land on which growing poor-land crops while building them into productive soils is a practice well suited to the requirements, resources, and abilities of the farmers on them. Farmers on the less productive soils of Kentucky are unanimous in the belief that without soil treatments lespedeza in a rotation increases the yield of the grain crops from 15 to 30%. There is reason to agree with them even though we have made no effort to ascertain its effect apart from liming or fertilizing, or both. However, lespedeza in a rotation with corn and wheat on each of which 300 pounds of 16% superphosphate were applied increased the corn yield 17.0% and the wheat yield 48.7% over a 6-year period. Soybeans instead of lespedeza decreased the yield of corn 0.7% and increased the wheat yield 26.8%. Cowpeas had practically the same effect as soybeans.

However, agronomists assume a grave responsibility in recommending even limited use of poor-land crops, at least on poor soils. The practice is so easy to follow that the farmer will continue it until both he and his soil are impoverished beyond redemption by his own resources. Therefore, while it may appear at times to be our duty to recommend crops suited to poor soils, it is even more our duty to point out the consequences of the improper use of this system of farming and to insist that unless it contributes permanently to soil building it is unprofitable to the farmer and to society.

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NATIVE GRASS BEHAVIOR AS AFFECTED BY PERIODIC CLIPPING[1]

W. B. GERNERT[2]

THE plant cover of native grasslands, commonly known in America as "The Prairie," is now being recognized as offering a very substantial foundation for solving the many crop and erosion control problems so enigmatically confronting this generation. With the extensive agricultural reconstruction activities in the Mississippi Valley, a great demand has arisen for more grass and soil cover. There are many who remember the tall, luxuriant bluestems, panic, Indian, and similar grasses which flourished in the eastern section of the prairies. These grasses were followed by bounteous crops for a number of years after they were plowed under. The writer can well remember personally burning off 80 acres of such grass—tall enough to get lost in—in order that he might "break" the sod more readily.

The material used in the study here reported was supplied by a virgin grass clipping project which has been under way at the Oklahoma Agricultural Experiment Station during the past 6 years. The present report deals with a special study of 12 of the 96 plats in comparison with the idle roadside and a pastured area with regard to certain perturbing questions which have become prominent and vital to a more complete understanding and clearer vision in the continuation of the project and to further research in this field.

THE SITUATION

The area under observation was restricted to a fenced and staked series of 96 small plats of native grass, each 8 by 12 feet in size; together with the surrounding, moderately grazed native pasture from which these plats were fenced off 6 years previously, and the unmolested strip of identical origin along the adjoining roadside. The location is an east exposure of a sloping hillside having a drop of 5 feet in 100, and on that vast area of lands known as the "Red Plains."

The soil of the area studied is identified by the U. S. Bureau of Soils (3)[3] as "Kirkland loam," originating in the Permian rocks of the Carboniferous age. It is described as being "brown in color rather than red—probably due to the long period of time during which it has been subjected to weathering, a soil in an advanced stage of development, with a—friable surface horizon and a rather well-developed granular structure and a low content of carbonates." This particular area discloses a rather compact, brownish-red, sandy subsoil beginning at varying depths of from 8 to 15 inches. Typical Kirkland loam has the following physical components:

	Sand, %	*Silt, %*	*Clay, %*
Surface	43.2	40.9	15.9
Subsurface	30.6	43.7	25.7

[1]Contribution from the Agronomy Department, Oklahoma Agricultural Experiment Station, Stillwater, Okla. Also presented at the Annual Meeting of the Society held at Chicago, Ill., December 5 and 6, 1935. Received for publication March 18, 1936.

[2]Associate Professor.

[3]Figures in parenthesis refer to "Literature Cited," p. 455.

THE CLIMATE

Rapid changes in temperature, moisture, and air movement are characteristic of the area, although the climate is preponderantly mild and pleasant. The mean annual temperature is 59.4° F, but readings of 110° have occurred with 55 consecutive days in 1934 reaching 100° or more. There have been 7 years recorded when the temperature did not mount to 100°. Scorching hot winds may accompany high temperatures. Both the coldest (—18°) and the warmest (90° F) winter temperatures have been registered in the month of February.

The average for the seven warmer months is above 70° and that of the five colder months, November to March, inclusive, above 40° F. The normal growing season for native grass is approximately 200 days, with the average date of first and last killing frosts approximately November 1 and April 1. Prevailing winds are from the south with north winds in December, January, and February. Air movements are most vigorous in March and April.

Local precipitation averages nearly 34 inches annually, with extremes of 16.79 inches in 1914 and 61.1 inches in 1908, both of which years preceeded the present investigation. Fortunately, the greater amounts of rainfall occur during the growing season, with the greatest monthly rain in May and the more torrential rains in the fall. Snows are usually light and of short duration. The effectiveness of the 34-inch precipitation is depreciated by a free surface water evaporation of more than twice as much, usually above 80 inches annually during the months of March to early November, inclusive, when water is not frozen. Atmospheric humidity is correspondingly low.

VEGETATION

The local grasses are typical of the region and the wide belt extending north and south from Canada to the Gulf through the eastern parts of the prairie states. Maps of native vegetation in the Mississippi Valley show three types of grasslands, *viz.*, bunch (tall grass), mat (short grass), and range (sparse vegetation). The virgin prairies of the Ohio, Wabash, and Illinois rivers were formerly occupied by somewhat similar vegetation. In order of dominance, the local unmolested grasses along the alleys of the plats and the roadside are as follows:

Little bluestem	(*Andropogon scoparius*)
Switch grass	(*Panicum virgatum*)
Indian grass	(*Sorghastrum nutans*)
Big bluestem	(*Andropogon furcatus*)
Blue grama	(*Bouteloua gracilis*)
Side-oat grama	(*Bouteloua curtipendula*)
Needlegrasses	(*Stipa* sp.)
Prairie three-awn	(*Aristida oligantha*)
Prairie dropseed	(*Sporobolus*)
Paspalums	(*P. stramineum*, *P. tradescantia*, and others)

The surrounding region of native grass is commonly referred to as "bluestem" or "tall grass" country.

IDENTIFICATION OF THE 14 GRASS PLATS

NO TREATMENT

B1 = No treatment, not clipped, check.

D10 = No treatment, not clipped, check.

Pasture = Pastured continuously since before 1890 (50 years). Controlled and grazed only by cattle since 1928. Mowed spring and fall. (96 plats fenced off in it in 1930.)

Roadside = Narrow, unclipped strip, 10 feet wide adjoining, with a deep ditch between the road and strip. (Rapid drainage.)

B3 = Clipped 6 years 2 times each year, on July 20 and Nov. 2.

C4 = Clipped 6 years 3 times annually, May 18, July 20, and Sept. 21.

D8 = Clipped 6 years 5 times, May 18, June 29, Aug. 10, Sept. 21, Nov. 2.

E6 = Clipped 6 years 8 times, beginning May 25 and at 21 day intervals until Oct. 19.

F9 = Clipped 6 years 9 times, May 18 to Nov. 2.

F6 = Clipped 6 years 10 times, April 27 to Nov. 2.

TREATED

(Manure and fertilizer were applied only once at the beginning of the experiment, clipped 6 years)

G3 = 10 tons of stable manure and 400 lbs. superphosphate (20% P_2O_5) per acre. Clipped 5 times, May 18, June 29, Aug. 10, Sept. 21, Nov. 2.

H3 = Same treatment as G3, clipped 2 times, July 20, Nov. 2.

G4 = 100 lbs. sodium nitrate ($NaNO_3$) per acre. Clipped 5 times, May 18, June 29, Aug. 10, Sept. 21, Nov. 2.

H4 = Same treatment as G4, clipped 2 times, July 20, Nov. 2.

The areas were selected to represent distinct types of clipping and no clipping, continuous pasture, and limited treatment with manure, phosphate, and nitrate of soda. The following points were studied: total clippings (5 years), comparative production (5th year), root weight (6th year), root volume (6th year), weight-volume factor, soil moisture (3 horizons, 6th year), soil organic matter (3 horizons, 6th year), soil pH (3 horizons, 6th year), sod slices mounted for study (3 horizons, 6th year), continuous controlled pasture, and unclipped and untreated.

RESULTS

Table 1 presents a summary of the observations made on the above-mentioned points.

On the basis of air-dry hay or clippings (secured with a hand sickle) and oven-dried weights with 15% added uniformly to all for "air dry" moisture, the "Air dry" figures are similar to farmer's hay production weights. Production of the 5th year shows that not enough additional yield is gained by 3 to 5 clippings to pay for the labor. Eight to 10 clippings annually produced much less total yield than 2 clippings. On the fertilized plats, two clippings produced considerably more than five clippings on similar plats.

Ellet and Carrier (5) conclude that on permanent bluegrass, "the total yield of dry matter varies inversely with the number of times the grass is cut during the growing season." Aldus (1) restates the same conclusion on prairie grass in Kansas. He also cites Crozier (4)

TABLE I.—*Native grass reactions in Payne County, North Central Oklahoma.*

Plat No.	Clippings per year (6 years)	Tons air-dry hay per acre, 1934 (5th year)	Root weight in grams per cylinder, 4⅛ × 5 in.	Root volume in cc per cylinder, 4⅛ × 5 in.	Weight/volume factor	Soil moisture %			Organic matter %			Soil pH		
						1–3 inches	6–9 inches	12–15 inches	1–3 inches	6–9 inches	12–15 inches	1–3 inches	6–9 inches	12–15 inches
B-3	2	1.02	11.2	21	0.5333	15.67	16.24	14.87	7.25	3.85	4.00	6.19	6.17	5.99
C-4	3	1.36	10.0	18	0.5559	15.66	14.26	16.02	5.70	4.15	2.90	5.94	6.28	6.19
D-8	5	1.22	13.4	34	0.3941	16.45	12.96	20.09	7.25	3.48	2.00	6.07	6.61	7.61
E-6	8	0.82	5.9	12	0.4916	15.91	13.80	10.80	7.60	3.70	3.60	5.97	6.09	6.31
F-9	9	0.92	5.5	13	0.4230	16.63	13.54	13.08	7.10	4.75	3.20	6.19	5.90	6.03
F-6	10	0.92	4.9	12	0.4083	16.06	14.62	11.66	7.90	3.80	3.80	5.99	6.09	6.10
G-3 MP	5	1.12	6.9	17	0.4058	17.07	11.44	16.05	6.95	4.40	3.80	6.02	6.51	6.78
H-3 MP	2	1.65	13.3	23	0.5782	17.74	15.89	14.70	9.80	4.45	4.15	6.30	6.35	6.62
G-4 N	5	1.26	6.0	10	0.6000	16.47	15.74	14.83	9.80	4.00	3.30	6.10	6.30	6.48
H-4 N	2	1.38	9.8	17	0.5764	17.37	13.38	17.25	7.70	4.45	3.90	6.16	6.12	6.36
B-1 check	0	0	13.2	22	0.6000	14.74	14.73	22.25	8.20	4.30	4.00	5.99	6.14	5.97
D-10 check	0	0	5.7	9	0.6333	13.24	14.18	18.13	7.40	3.70	2.90	6.28	6.45	6.87
Pasture	?	?	3.6	7	0.5142	16.82	14.14	14.96	7.00	3.90	3.10	6.28	5.97	6.36
Roadside	0	0	19.6	31	0.6322	16.54	18.69	16.30	5.40	4.50	3.80	6.28	6.10	6.07
Average			9.21	17.6	0.5247	16.16	14.54	15.83	7.50	4.10	3.46	6.13	6.22	6.41

finding similar results on cultivated grasses. Weaver and Fitzpatrick (10) state, "Practically all of the prairies have been mowed annually, some for a period of more than 50 years. It has been repeatedly demonstrated that removal of the plant cover after it is mature has no harmful effect upon the vegetation." This is a point to which grass students might well give further scrutiny.

To avoid disturbing a large area of the tiny 8 by 12 foot plats, a small "standard" sod sampling tool was used with a plunger for removing sods 4⅛ inches in diameter and 5 inches deep. Identical and representative sods were thus taken from each of 14 situations. The above-ground vegetation, together with all plant residue, was shaved off at the surface of the soil cylinders which were then placed in gallon cans of water 24 hours to soften the soil. The sample mass was washed into a 20-mesh screen where the washing of the roots was finished with a power spray. After drying till surface water was no longer visible, the last soil particles were removed by hand picking.

Root volume was determined by placing these roots, free of external water, in a dry, graduated cylinder of 250-cc capacity. A previously measured quantity of water (150 cc) was then poured over the root mass. The increased reading gave the root volume by subtraction. The graduate was bounced on the table to remove all visible air bubbles.

Plat D8, which had been clipped 30 times in 6 years, produced the greatest root volume, the roadside second, and one of the manure and phosphate treated plats third. The pasture sample returned the lowest yield of roots by volume, considerably lower than the plats clipped 8, 9, and 10 times.

After the volume was taken, the roots were dried 2 days in an electric oven at 110° C. Since no accepted factor for the average water content of air-dry native grass roots is available, the weights in grams were recorded on a water-free basis. Root weight is correlated with above-ground production evidently, but shows much greater variation. The roadside root sample produced much the greatest weight but not the greatest volume. The pasture sample was lowest of all in weight and one of the check plats which was not clipped for 6 years was also very low, showing that a long period of time may be required for the recuperation of underground grass parts.

Results by Weaver and Harmon (9) indicate that more than half of the roots of vigorous grasses may be found in the upper 4 inches of soil. In the present investigation with impoverished grasses, considerably more than three-fourths the total root mass was obtained in the upper 5 inches as was indicated by examination of the deeper horizon before the hole was filled to facilitate resodding. (See Fig. 1.)

It is significant that root volume expressed in cubic centimeters shows greater production and variation than does root weight in grams. This might indicate grams to be the coarser measure. That this is not due to choice of measurement units but rather to variability in root structure, which is indicative of vigor and activity, is evident. The average root volume in cubic centimeters at the bottom of the table is approximately twice that of root weight in grams.

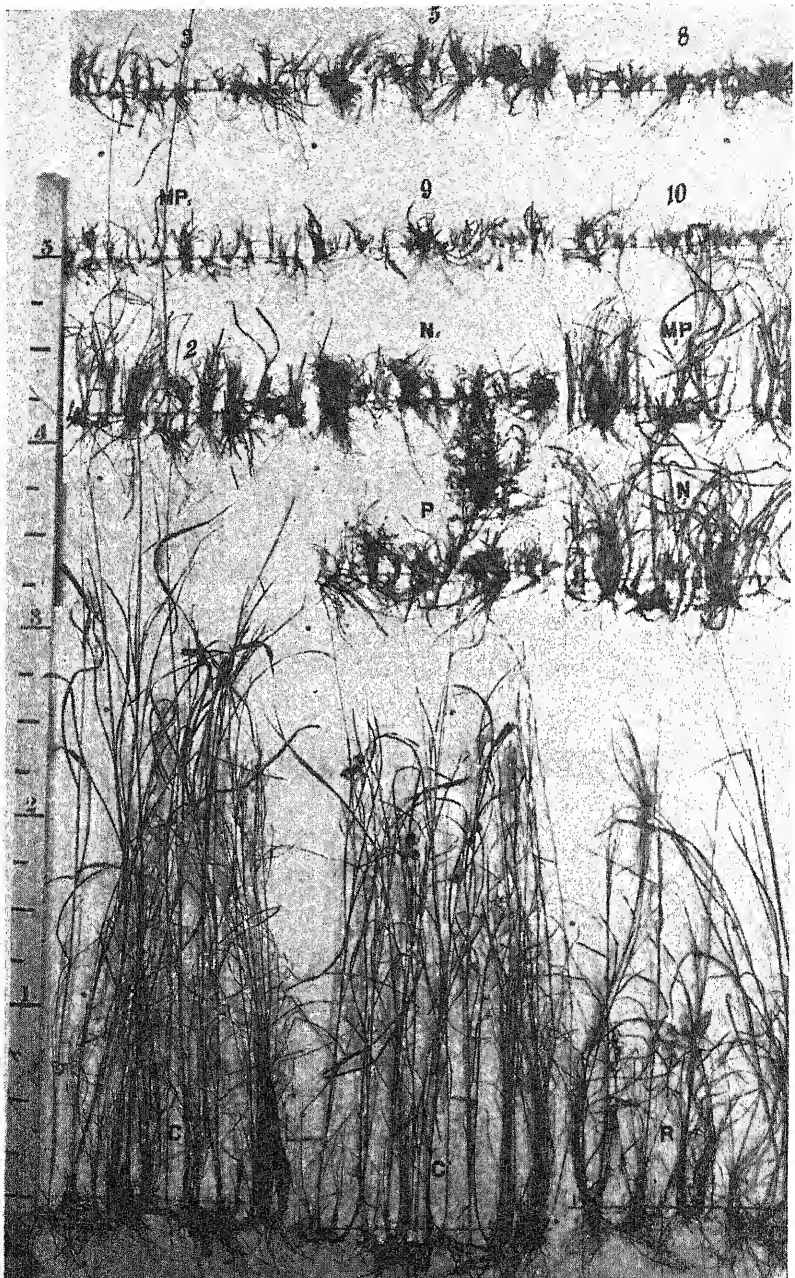

FIG. 1.—Native sod panels. Panels 20 × 3 × 8 inches deep were removed while the soil was moist, washed carefully, and mounted in their relative position and distribution. Plats clipped less frequently, fertilized, or left uncut exhibit the more dense and heavier growth of both root and above-ground vegetation. These sod sections were secured just before the time of the last clip of the season, Nov. 2.

The combined values of root weight and root volume expressed in a weight-volume factor affords an opportunity to study the two simultaneously. It is possible that this factor is a more dependable evaluation of root development. The grass plats showing the greatest above-ground growth yield the large root weight-volume factors with but few exceptions. (See Fig. 1.)

Soil moisture at three depths, 1 to 3 inches, 6 to 9 inches, and 12 to 15 inches, was obtained by removing tube-core samples of soil $1\frac{5}{16}$ inches in diameter, drying them 2 days in a 110° C electric oven and weighing direct in grams. Surface soil moisture on November 16 was higher on frequently clipped plats and on the pasture than on those clipped less often, also approximately 2% higher than on the two check plats.

While the rainfall run-off would be greater, undoubtedly, on the plats more nearly bare, the possible rain interception by the plants of the taller growing grasses would alone account for the difference in surface soil moisture of the plats. Horton (6) has shown that plants may intercept from 25 to 100% of light rains which never reach the soil underneath. He found that narrow-leafed and narrow-stemmed plants, such as grasses and evergreen trees, caught a far greater proportion of rain than did the broader-leaved trees, shrubs, and herbs. The possibilities of rainfall interception are indicated by the plat samples shown in Fig. 1.

Moisture at the 6 to 9 inch soil depth was decidedly less than surface soil moisture in the frequently clipped plats, approximately equal in the two checks and highest in the roadside sample. The average of 6 to 9 inch soil depth moisture was 1.62% less than the surface soil horizon moisture and 1.29% less than the moisture in the 12 to 15 inch horizon. Soil moisture in the 12 to 15 inch horizon was intermediate between that of the surface and the second horizon. The greatest amount (22.25%) was found in one of the unclipped plats and in the deepest horizon.

A total of 19 inches of rain fell from July 18 to November 15, with six rains exceeding 1 inch in amount in the season (1935) in which these tests were made. Total rainfall at Stillwater for the year was 33.59 inches, one-third of which fell in the month of June.

Organic matter was determined by the Schollenberger method (7) with duplicate samples obtained at the various depths and by the same method as that used for soil moisture samples. Half of the composite sample was used for organic matter determination and half for pH determination.

Weaver and Harmon (9), say, "Fortunately, the disappearance of dead organic matter from the soil is very slow, and even in bared soil it may remain during a long period of years." On the other hand, sod is reputed to be one of the most rapid contributors to soil organic matter, and increased organic matter has been called (2) the "by-product of good farming." On old fields which have been cultivated many years, with or without the addition of chemical fertilizers, the soil becomes sad and tight, sticky when wet and is very difficult to cultivate.

If the loss of organic matter is slow, as stated, the rapid degeneration of occupied soils must be due to the organic matter condition rather than amount, but quoting again, "The amount of organic matter largely determines the productive power of the soil" in arid as well as humid regions. The rapidity with which favorable organic matter content of soils is regained by means of grass and legume culture is also stated in the literature (8).

As shown in Table 1, the organic matter content in the lower horizon of the frequently clipped plats was less than that of the least frequently clipped plats, but one of the check plats was also low. By way of possible illumination, this plat and horizon is highest in pH. Organic matter diminished nearly one half on the average on all plats in the deepest horizon. The high surface horizon readings obtained from two fertilized plats, H3 and G4, may have been caused by root response to fertilizer, although two similarly treated plats failed to equal the high figure. Apparently, soil organic matter and live root weight and volume are not necessarily directly correlated, nor does it appear that live roots use up any considerable quantity of the soil organic matter.

The quinhydrone (electrolitic) method was used for determination of pH. The remaining half of the composite sample used for organic matter determination was available for this work. Based on the theory that soil acidity is due largely to crop removal and accompanying decrease in calcium, together with other alkaline salt removal, we might expect that the roadside area and the two check plats which had not been clipped during the past 6 years would show a relatively higher pH. One of the plats receiving manure and phosphate 6 years previously but clipped only twice annually was slightly highest in pH, with the roadside, pasture, and one of the check plats following closely. The lower readings were obtained on the untreated plat clipped 3 times, on those clipped 8 times and 10 times, and on one of the checks which was high in organic matter in the upper horizon.

In the 6 to 9 inch soil horizon the highest pH reading was found in the plat with the lowest organic matter content, C4. The lowest pH in this zone was found on the plat with the highest organic matter content and the next to the highest clipping frequency, F9. The pasture exhibited the second lowest pH.

Both the lowest and the highest pH of the 12 to 15 inch horizon were found on the two unclipped (check) plats and the next two highest on the plats receiving manure and phosphate. The second lowest pH was found on plat B3, clipped twice annually. The horizon averages increased with the depth and inversely with decrease in organic matter, as is to be expected in this climate and soil.

SUMMARY

1. Clipping native grass more than twice annually did not return enough additional production in the fifth year to pay for the labor. As the number of clippings increased, production declined.

2. The greatest yield of air-dry hay was obtained from the plat clipped twice and treated with barnyard manure 6 years previously at the rate of 10 tons with 400 pounds of 20% phosphate per acre.

3. The least top weight was secured from plats clipped 8, 9, and 10 times annually.

4. The greatest root weight was obtained from the unmolested roadside grass and the next greatest root weight from an untreated plat clipped five times annually, from one plat clipped only twice annually but receiving an initial treatment of manure and phosphorus, and from one of the check plats.

5. The lowest production of roots by weight came from plats clipped most frequently and which also produced the least top weight.

6. The greatest root volume was obtained from the plats exhibiting greatest root weight.

7. The lowest root volume was found on the pastured area, on one of the check plats, on the manured plat, and on the plat clipped 10 times annually.

8. The roadside, check, and nitrated plats and one manured plat produced the highest root weight-volume factor.

9. Lower root weight-volume factors were obtained on those areas clipped more frequently.

10. Soil moisture was greatest on unclipped plats and larger in the various horizons on plats less frequently clipped. For the average of the 14 plats the 1 to 3 inch horizon contained the most soil moisture, the 12 to 15 inch horizon ranked second, and the 6 to 9 inch horizon third in the sixth year.

11. The lowest soil moisture in the upper horizon was found in the unclipped plats; in the second horizon, curiously, in one of the plats receiving manure and phosphate; and in the third horizon, in the most frequently clipped plats, as would be expected.

12. Soil organic matter was greatest in the upper horizons and in one of the plats receiving manure and phosphate, in one of the plats receiving $NaNO_3$, and in one of the unclipped plats.

13. Low soil organic matter was not always found where expected and is apparently not associated with the amount of live roots. If soil organic matter content is quite permanently residual, it must be the result of previous vegetative growth.

14. The pH was highest in the upper horizon on plats manured and phosphated but clipped only twice annually. It was also high on unclipped, pastured, and roadside plats, but was highest in the lower (12 to 15 inch) horizon of plats clipped five times, one of which received manure and phosphate. An unclipped plat was also high. The lower horizon produced the highest average pH readings.

15. The lowest pH reading was found in the 6 to 9 inch soil horizon of a plat clipped nine times annually. Other low pH readings were distributed through the various horizons.

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KINGWA SOYBEANS[1]

R. J. Garber[2]

A NEW pure-line variety of soybeans developed on the agronomy farm of the West Virginia Agricultural Experiment Station is described and named Pekwa in Bulletin 247 of that Station issued in 1932. On the last page of the bulletin mention is made in a footnote of another pure-line selection also developed at the West Virginia Agricultural Experiment Station and named Kingwa. These new varieties, which are practically indistinguishable, came from individual plant selections of the commercial Peking variety. The purpose of this paper is to present evidence that makes it seem desirable to substitute the name Kingwa for Pekwa and to discontinue distribution of the strain now grown under the name of Kingwa.

Since the above-mentioned bulletin was published, Kingwa has become well established in southern Indiana and the seed of this variety is handled by commercial seedsmen. The acreage in Pekwa, on the other hand, is confined largely to certain sections in West Virginia and the seed of this variety is not so well established in the seed trade. A brief history of the introduction of Kingwa into Indiana may be of interest.

Seed of the two pure-line selections, I–21–7 (later named Pekwa) and I–21–8 (later named Kingwa), was exhibited in the "Better Crops Exhibit" by West Virginia University in 1927 at the International Grain and Hay Show held at Chicago, Illinois. M. O. Pence, extension agronomist of Purdue University, obtained seed of I–21–8 and turned it over to the Agronomy Department of the Indiana Experiment Station for testing. In 1928 the variety was included in the soybean variety trials at Lafayette, and in 1929 the seed stock was increased. In the spring of 1930, 2 bushels of Kingwa were supplied to Henry L. Hahn, a farmer near Evansville, Indiana. In 1931, 200 bushels of his crop were certified and since then the acreage of Kingwa has steadily increased in southern Indiana. In some areas Kingwa is the only variety of soybeans that is grown at present.

In the comparative yield trials of Pekwa and Kingwa at Morgantown, W. Va., carried on for a period of 12 years, no significant difference in yielding ability either of hay or seed has been found between these varieties. The average annual yields as determined in rod-row plats replicated four or five times are shown in Table 1.

It is apparent from the data presented in Table 1 that Pekwa and Kingwa do not differ significantly in yielding ability of either hay or seed when grown under conditions that obtain on the agronomy farm near Morgantown, W. Va.

The same two strains of soybeans have been grown in comparable variety trials during a period of 4 years by the Purdue Agricultural

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TABLE 1.—*Average yields of seed in bushels per acre and of hay in tons per acre of Pekwa and Kingwa soybeans grown during a period of 12 years in comparative two-row plats near Morgantown, W. Va.*

Variety	Average annual yields per acre												Grand av.
	Seed in Bushels												
Pekwa	37.8	20.3	25.3	20.3	21.3	28.3	17.3	32.7	27.6	18.0	17.3	26.6	24.4
Kingwa	36.8	20.5	24.2	22.9	20.8	29.2	18.1	31.1	30.7	18.5	16.0	26.1	24.6
	Hay in Tons												
Pekwa	2.82	2.16	2.49	2.01	2.33	1.75	1.49	2.20	1.99	1.57	1.73	1.72	2.02
Kingwa	2.90	2.40	2.16	2.08	2.27	1.89	1.38	2.15	2.37	1.53	1.60	1.70	2.04

Experiment Station at Lafayette, Indiana. The seed and hay yields which were kindly furnished to the writer by R. R. Mulvey are shown in Table 2. The data from Indiana corroborate those obtained in West Virginia in showing no significant difference in yielding ability between Pekwa and Kingwa.

TABLE 2.—*Average yields of seed in bushels per acre and of hay in tons per acre of Pekwa and Kingwa soybeans grown during a period of 4 years in comparable plats near Lafayette, Ind.*

Variety	Average annual yields per acre				Grand av.
	Seed in Bushels				
Pekwa	38.9	25.0	25.6	35.9	31.4
Kingwa	36.2	24.9	25.0	33.7	30.0
	Hay in Tons				
Pekwa	3.25	1.85	1.90	3.09	2.52
Kingwa	3.04	1.88	1.95	3.15	2.50

At the Ohio Agricultural Experiment Station Pekwa and Kingwa have been compared during 2 years. The yield data collected in these tests and kindly furnished by J. B. Park of that station indicate no significant difference between the two varieties.

The data presented above, together with other similar data, show conclusively that Pekwa and Kingwa are very similar in yielding ability. There is also a striking resemblance between the two varieties with respect to other characteristics. Both have marked ability to retain their leaves even after the pods are ripe; both have relatively fine stems and an erect growth habit, although Pekwa is inclined to be somewhat more erect than is Kingwa. Kingwa is perhaps a few days later in maturing, is somewhat less uniform, and has slightly smaller seeds than Pekwa. It is extremely difficult if not impossible to distinguish these two varieties when growing side by side.

At the time (1931) Pekwa was named and was being distributed in West Virginia, Kingwa was being increased in southern Indiana. Owing largely to the fact that the latter region includes a relatively extensive soybean growing area, whereas the area devoted to this crop in West Virginia is rather small and scattered, Kingwa has increased more rapidly than has Pekwa. In fact, Kingwa has become quite well established in commercial channels, while Pekwa is known chiefly in West Virginia.[3]

Soybean growing areas other than those in Indiana and West Virginia are considering growing one of these two varieties and inasmuch as the two are so similar, it seems unwise to continue to distribute both of them and attempt to maintain their purity, particularly where they are grown near one another in the same region.

At a recent meeting of agronomists representing the states concerned, it was proposed to continue to increase and distribute only one of these two strains and to adopt the name *Kingwa* because it is commercially established. Inasmuch as selection I–21–7 (the strain at present grown under the name of Pekwa) is more uniform and has a somewhat more erect habit of growth than selection I–21–8 (the strain at present grown under the name Kingwa), it was suggested that henceforth selection I–21–7 only be increased and distributed under the name Kingwa. There is not enough difference between the two strains to justify carrying both under two names, so the above suggestions have been accepted by the West Virginia Agricultural Experiment Station. *The pure line selection I–21–7 made from the Peking variety and formerly named Pekwa is hereby renamed Kingwa and, at the proper time, application for registration under this name will be made.*

[3]At the time selection I–21–7 was named Pekwa by the West Virginia Agricultural Experiment Station it was expected that selection I–21–8 would be suppressed. However, the latter had already established a satisfactory record in southern Indiana and selection I–21–7 was unknown to that region. As a result of this situation, and at the suggestion of K. E. Beeson, extension agronomist of Indiana, selection I–21–8 was named Kingwa as mentioned previously.

PREDICTION OF DOUBLE CROSS YIELDS IN CORN[1]

C. W. DOXTATOR AND I. J. JOHNSON[2]

WHEN four satisfactory inbred lines of corn are to be used in a double cross, it is necessary to know how these can be combined to obtain the best possible double cross.

Jenkins,[3] in estimating the probable performance of double crosses, concluded that inbred-variety crosses were advantageous in the selection of inbred lines which will combine best in double crosses. Another of the methods of estimation used was to determine the combining ability of four of the six single crosses which can be produced by the crossing of four inbred lines in all possible combinations. Obviously, in the hybridization of two single crosses, the parent single cross combinations are not involved in the yield of the double cross. It is, therefore, theoretically possible to obtain three different yielding double crosses from four inbred lines by the use of different single cross parents. For example, the expected yield of a double cross (a × b) (c × d) is obtained from the average yield of the four single crosses a × c, a × d, b × c, and b × d. If the yields of the six single cross combinations from four inbred lines are different, the expected yield of the three possible double crosses will also be different. Although the inbred variety cross appears to be a desirable method of selecting inbred lines for use in double crosses, single cross data from any four selected lines should therefore be of value in determining which of the three possible double crosses are most productive.

The data herein reported were obtained in 1935 at University Southeast Branch Experiment Station, Waseca, and at University Farm, St. Paul, Minn. At the Waseca station four inbred lines, cultures 11, 14, 374, and 375, which are being used in a double cross and are in convergent improvement studies, were available in the six single and three double cross combinations. Two three-way crosses were also available. Cultures 11 and 14 are inbreds of medium early Minn. 13 and cultures 374 and 375 are inbreds of yellow corn and are extremely late in maturity. From previous tests for several years these inbreds were known to have desirable combining ability. The 11 crosses and a check hybrid were grown in six replicates of three-row plats. Only three stalk hills in uniform competition were harvested and in no case was a yield figure based on less than 10 hills. The mean yields of the crosses and the analysis of variance for the experiment are given in Table 1.

In the study made at University Farm, four double crosses from Northwestern Dent inbred lines were grown together with the single crosses needed for the prediction of their yields. The crosses were planned so as to determine the yields obtained from two double

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[2]Instructor and Assistant Professor, respectively.

[3]JENKINS, MERLE T. Methods of estimating the performance of double crosses in corn. Jour. Amer. Soc. Agron., 26:199–204. 1934.

TABLE 1.—*Yields and analysis of variance of six single, three double, and two three-way crosses from four inbred lines of corn.*

Key	Hybrid	Yield in bus. per acre	Hybrid	Yield in bus. per acre
(A)	11×14	56.98	(11×14) (374×375)	78.70
(B)	11×374	88.67	(11×374) (14×375)	66.33
(C)	11×375	88.87	(11×375) (14×374)	70.58
(D)	14×374	85.18	(11×14) 374	81.67
(E)	14×375	79.48	(11×14) 375	82.83
(F)	374×375	52.13	Minhybrid 301	83.02

Source of variation	D.F.	Sum of squares	Mean square	F	Standard error of mean
Blocks....	5	64.84	12.968		
Crosses....	11	9,667.98	878.907	70.12	
Error.....	55	689.37	12.534		1.45
Total....	71	10,422.19			

crosses made between different single cross parents from the same four inbred lines. Two such comparisons are available. Six replicates of each cross were planted in single-row plats. Only three stalk hills surrounded by hills of corn were harvested for yield. The yields of the single crosses, the four double crosses, and of standard Northwestern Dent are given in Table 2.

TABLE 2.—*Average yields in bushels per acre of the single crosses used in the prediction of double cross yields and the yields of four double crosses between them.*

Key	Hybrid	Yield in bushels per acre	Key	Hybrid	Yield in bushels per acre
(G)	62×64	31.4	(N)	66×68	62.1
(H)	62×66	58.8	(O)	67×68	38.8
(I)	62×67	28.5	—	(62×66) (67×68)	41.8
(J)	62×68	17.1	—	(62×67) (66×68)	48.4
(K)	64×66	48.6	—	(64×66) (62×68)	54.1
(L)	64×68	37.7	—	(64×68) (62×66)	44.5
(M)	66×67	58.9	—	N. W. Dent	50.1

Standard error of the mean = 1.60 bu.

In predicting the yields of the double crosses, the yields of the four single crosses not used as parents were averaged. The predicted yields of the three-way crosses were based on the average yield obtained from the two single crosses made between the two inbred lines used in the single cross and the inbred line used as the male parent in the three-way cross. In Table 3 are given the actual yields of the double and three-way crosses, together with the predicted yields based on the single cross yields used in their prediction.

In the results from the Waseca station, the double cross (11 × 14) (374 × 375) yielded 12.37 bushels higher than (11 × 374) (14 × 375) and 8.12 bushels higher than (11 × 375) (14 × 374). These differences are highly significant. By the use of the appropriate single crosses for prediction of yields, a very good agreement to the actual

yields has been obtained. The combination (11 × 14) (374 × 375) has been selected as the most desirable. The predicted yields of the two three-way crosses were even greater than for the most promising double cross. The experimental results from these three-way crosses are in accord with the prediction.

TABLE 3.—*Actual and predicted yields of double and three-way crosses.*

Hybrid	Yield in bus. per acre		Single crosses averaged for predicted yields
	Obtained	Predicted	
Waseca Branch Station			
(11×14) (374×375)	78.70	85.55	B, C, D, E
(11×374) (14×375)	66.33	70.79	A, C, D, F
(11×375) (14×374)	70.58	69.31	A, B, E, F
(11×14) 374	81.67	86.92	B, D
(11×14) 375	82.83	84.17	C, E
University Farm			
(62×67) (66×68)	48.4	43.4	H, J, M, O
(62×66) (67×68)	41.8	41.7	I, J, M, N
(64×66) (62×68)	54.1	47.5	G, L, H, N
(64×68) (62×66)	44.5	39.8	G, K, J, N

The yields of the two Northwestern Dent double crosses (62 × 67) (66 × 68) and (62 × 66) (67 × 68) made between different single cross parents from the same four inbred lines should have been different on the basis of their predicted yield, the greater yield being expected from the former. Actually, the crosses differed by 6.6 bushels per acre, a highly significant difference in accord with the prediction.

Similarly, the yields of the two double crosses (64 × 66) (62 × 68) and (64 × 68) (62 × 66) made from the same four inbred lines differ in their predicted and actual yields. With these two double crosses, the yields obtained differed by 9.6 bushels per acre. The odds for the significance of these differences exceeds 99:1.

SUMMARY

From the results obtained in these experiments it appears that highly significant differences in yielding ability can be found in double crosses resulting from the use of different single cross parents produced from four inbred lines. The results obtained also indicate that by the appropriate use of single cross data, the highest yielding double cross combination may be predicted.

HUMIDITY CONTROL IN LARGE CHAMBERS BY MEANS OF SULFURIC ACID SOLUTIONS[1]

Frank J. Zink and C. O. Grandfield[2]

THE need of controlling humidity along with temperature control in relation to two problems under investigation, *viz.*, the influence of atmospheric humidity on the rate of drying of alfalfa and the effect of humidity on the seed setting of alfalfa plants, resulted in the construction of a simple and accurate method which is described herein as a guide to other investigators confronted with a similar need.

As the necessary equipment was not available, search of the literature on humidity control was made to find some reference to an inexpensive method to meet the requirements. Most of the methods of obtaining variable humidity control with spray jets for humidifying and refrigerating systems for dehumidifying are commercial units built largely for air conditioning of buildings and do not permit a sufficiently accurate control within the range suitable for research work.

Satisfactory humidity control by means of supersaturated salt solutions is reported by Spencer (1)[3] and a number of other investigators. Each salt used provides for only one condition of humidity, rather than a range of conditions. In other investigations humidity control has been obtained by aqueous solutions of sulfuric acid (2). By varying the concentration of the acid, any desired degree of humidity may be obtained. The majority of these studies used sulfuric acid with desiccators or other small enclosed chambers (3). Zink (4) used sulfuric acid in desiccators for this purpose in studies of equilibrium moistures of hays.

From the experience of using acid in desiccators and information on the specific limit of size of enclosed space found in the literature, it seemed possible to enlarge the space conditioned and to increase the quantity of acid in a ratio similar to that used in desiccators to a point where large cabinets might be used. The basic method has been reported on by Wilson (5) who gives a graph and states the thermodynamic theory of the calculation.

In the studies reported in this paper the first efforts were confined to bubbling air through acid solutions of different specific gravity and directing the conditioned air into an enclosed space of approximately 5 cubic feet. This means has served for small bulbous glass chambers and possibly would serve for a chamber of larger size if a good diffusion of air and acid could be obtained, or if large volumes of acid could be used in a closed chamber. The variable results obtained

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[2]Associate Professor of Agricultural Engineering, Kansas Agricultural Experiment Station and Assistant Agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 466.

were attributed to condensation of moisture in the tubing leading to the chamber and also to the fact that the specific gravity of the acid was changed constantly through the loss or addition of moisture.

Following these trials, glass dishes similar to photographer's developing trays were used in the chambers. A number of these containers could be used, thereby regulating the amount of acid surface exposed. The acid exposed in trays served much better for humidity control than the bubbling method. After a few hours of control, however, the formation of a scum or a stratification of the surface apparently occurred and some agitation of the acid was necessary to re-establish diffusion. A small fan was placed in the chamber for this purpose and gave satisfactory results.

Based on the experiences obtained in the small experimental cabinet, two larger cabinets, one containing 9 cubic feet of air space and the other 56 cubic feet, were designed to fit the problems for which the work was intended. Any desired relative humidity could be obtained by using acid of the required specific gravity. The specific gravity is measured with hydrometers ranging from 1.000 to 2.000, reading to 0.002. Only a small original supply of acid is necessary as it can be used repeatedly. When different densities are desired, the acid, before placing it in the cabinet, may be diluted by adding water or concentrated by evaporating water from it by using dry air. Small fans were used to increase the molecular absorption and diffusion of the surface of the acid and to prevent stratification on the surface.

RESULTS

The results obtained are shown in Figs. 1 and 2 and are considered highly satisfactory. Periods of accurate control varied in length from a few hours to 10 days. The range of humidity control was from near 0 to 90% at temperatures varying from 50 to 110° F. Reference to the basic diagram of Wilson (5) indicates that any desired humidity condition may be obtained over a range of temperatures from 0 to 75° C. The range of constant humidity control may be seen from the graphic records.

Fig. 1 shows two charts from a hygro-thermograph in the small cabinet, covering a period of 48 hours. Charts A and B illustrate the control of humidity by means of sulfuric acid under different degrees of temperature and rates of temperature fluctuation. Where the temperature as shown in chart A was lowered abruptly from 95° to 85° F, the humidity without control would have risen temporarily, but by dehumidifying with dry air from a low temperature chamber the humidity was held to a relatively straight line. As shown in chart B, under gradual changes in temperature of not too wide range, the humidity is not affected.

Fig. 2 shows charts A and B obtained in the large cabinet under different ranges of temperature and humidity than those shown in Fig. 1. In chart B the relative humidity was changed by the addition of water to the acid. In approximately 2 hours, the relative humidity was established at the new level. This chart was made when samples were being removed from the cabinet at intervals and consequently shows a saw-tooth effect.

There are a number of limitations of the method, which if understood and considered in the design of the apparatus for its application, need not interfere with its uses. For example if the materials under observation give up or absorb much water, this water has to be absorbed by or given up by the acid solution. Such exchanges alter the specific gravity of the acid and hence set up different conditions. If the samples are small and only a small amount of moisture is to be absorbed or released by the acid no appreciable change in hu-

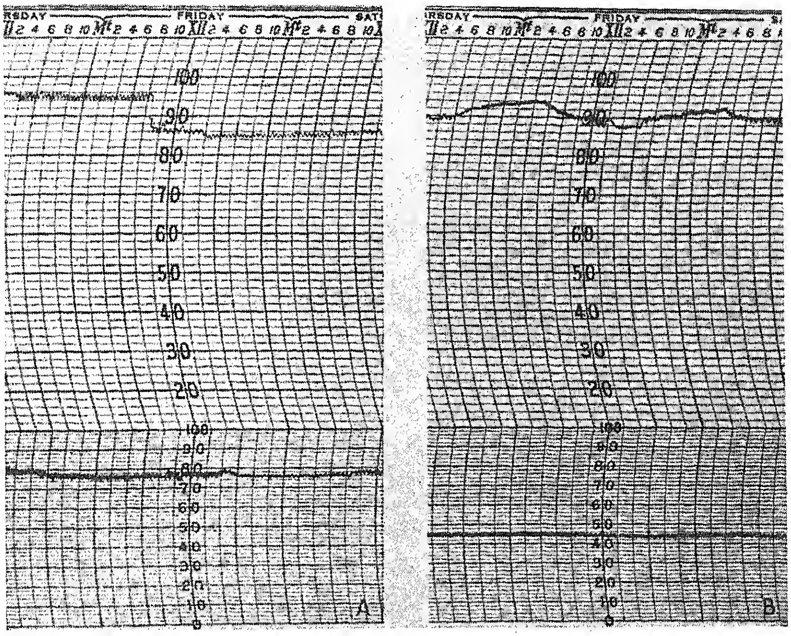

FIG. 1.—Hygro-thermograph records of 48 hours duration, showing humidity control in a 9 cu. ft. cabinet. Upper line temperature; lower line humidity.

midity will occur. In the study of the drying rate of alfalfa, samples of 50 stalks did not change the specific gravity of the acid solution. If larger samples were to be used, the volume of acid should be increased accordingly. If this were done, no appreciable change in the specific gravity of the solution would occur and suitable constant humidity conditions would be maintained. However, with growing plants, it was necessary to dehumidify during the middle of the day because of the different rates of respiration between night and day. The respiration during a part of the day was faster than the moisture from the air would diffuse with the acid. This was taken care of by dehumidifying with dry air from the outside if sufficiently low in humidity or from a low temperature chamber for the lower humidities.

From the results obtained in this work it is apparent that, with limitations, if understood, the use of sulfuric acid as a means of hu-

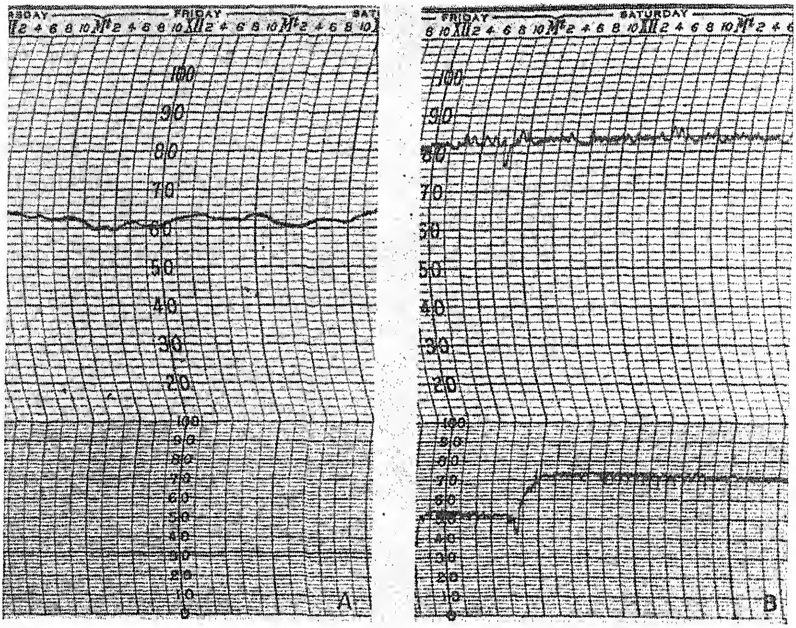

FIG. 2.—Hygro-thermograph records of 48 hours duration, showing humidity control in a 56 cu. ft. cabinet. Upper line temperature; lower line humidity.

midity control is satisfactory in conducting agricultural research of certain types. This method of control has the advantage of low cost, simplicity, and accuracy under temperature controlled conditions. More extensive work should develop convenient equipment for many problems.

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INHERITANCE OF RESISTANCE TO *USTILAGO LEVIS* (K & S) MAGN. (COVERED SMUT) IN A CROSS BETWEEN MARKTON AND COLORADO 37 OATS[1]

W. W. Austin and D. W. Robertson[2]

COVERED smut caused by *Ustilago levis* (K & S) Magn. is responsible to a large degree for the heavy yearly losses in yield suffered by many farmers throughout the irrigated section of Colorado. This is especially true where the farmer does not use a chemical seed treatment for control.

The problem of breeding for resistance to smut in oats and the manner of inheritance has been studied by a number of investigators. Difficulty has been experienced by most workers in obtaining a satisfactory epidemic in the field. This condition, along with the existence of several physiologic forms, has complicated the problem of determining the number and nature of genetic factors involved.

The purpose of this investigation was to study the mode of inheritance of *Ustilago levis* in a cross between Markton and Colorado 37 oats, and to attempt to produce true-breeding, smut-resistant strains having the desirable characters of both parents.

REVIEW OF LITERATURE

The inheritance of resistance to smut in oats has been studied by several workers. Wakabayashi (12)[3] published the first report in this country on inheritance of smut resistance in oats. He worked with Red Rustproof, which is resistant to covered smut, and Black Tartarian, which is susceptible. He concluded several genetic factors were involved and that resistance was dominant.

Barney (1), working with Turkish Rustproof × Gold Rain, Swedish Select × Burt, and Fulghum × Black Mesdag, concluded smut resistance was controlled by one, two, and three independent factors, respectively.

Reed (8) found resistance dominant to susceptibility in a cross between Black Mesdag and Hull-less. He also (9) studied the inheritance of resistance to smut infection and found the segregation in the F_2 apparently to be on the basis of a single factor difference.

Gaines (3), working with Markton as the resistant parent, states that it probably contains three factors for smut resistance.

Hayes, Griffee, Stevenson, and Lunden (5), working with a cross between a homozygous strain (White Russian × Minota) Minnesota No. 11-18-37 and Black Mesdag, state that there are separate factors which differentiate immunity and resistance, respectively, located in Black Mesdag. The factor pair II might be considered to be epistatic to the factor pair RR. A mixture of both smuts was used in this study.

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[3]Figures in parenthesis refer to "Literature Cited", p. 471.

Garber, Giddings, and Hoover (4) studied the inheritance of smut infection in the cross Gopher × Black Mesdag. Gopher is moderately susceptible to both loose and covered smuts and Black Mesdag is immune. It was found they differ in their reaction to smut infection by a single main factor, and, in addition, by at least one modifying factor which resulted in transgressive segregation for susceptibility. They suggest that I might act as an inhibitor to R, or as an additional factor for resistance but less potent than R.

Welsh (11) studied the cross Victory × (Minota-White Russian × Black Mesdag) and found evidence of transgressive segregation in families inoculated with loose and covered smuts. The results indicate that at least two factors govern the inheritance of smut reaction in this cross.

Coffman, *et al.* (2) studied crosses between Markton and several common oat varieties. They state the results obtained from this study give reason to doubt the existence in Markton of three factors for resistance to all *Ustilago levis* strains. Transgressive segregation was observed; however, they were unable to make a factorial genetic analysis of their data.

Stanton, Reed, and Coffman (10) infected a Markton × Black Mesdag cross with *Ustilago avenae*. Both parents were infected with the same smut before planting. No smutty plants developed; however, a marked infection did develop in the F_3 progenies. This might be explained, they say, by the presence of complementary factors for susceptibility, which when brought together through hybridization may produce infected plants.

Johnson (6), working with a Black Mesdag × Victory cross, concluded that a two-factor difference existed between the parents, Black Mesdag possessing the dominant factors and Victory the recessive allelomorph of these factors.

MATERIALS AND METHODS

Markton (C. I. No. 2053), which has been found highly resistant to both species of smuts by several workers, was used as the resistant parent. Colorado 37 (C. I. No. 1640), a high-yielding, thin-hulled, midseason oat of Swedish type, was used as the susceptible parent.

In the spring of 1931, crosses were made between the above-named varieties. Three F_1 plants were produced from the cross Colorado 37 × Markton. Only one plant was produced from the reciprocal cross. All F_1 plants were of the Markton type. The F_1 plants were threshed and dehulled as described by Reed (7). The inoculum used in smutting the F_1's was collected from a field of Colorado 37 growing at the Colorado Experiment Station. The smut was identified as *Ustilago levis*. The inoculum was prepared by grinding the smutted panicles and sifting the ground material through a fine sieve. A germination test was made on the collection and the smut spores were found to be approximately 90% viable. Inoculations were made by placing a liberal amount of inoculum in each envelope with the dehulled seed and shaking vigorously. The seed was then space-planted 2 or 3 inches apart in 18-foot rows. Two hundred seeds of each parent were also dehulled, smutted, and planted. In the fall all the plants were pulled, counted for smut, and threshed separately.

One hundred seeds from each plant were dehulled and smutted during the winter. The following spring, the F_2 seeds were planted in 8-foot rows. Seed of each parent was dehulled, inoculated with smut, and check-rows planted at 25-row intervals along with the F_3's.

EXPERIMENTAL DATA

At time of heading, segregation for plant type and color was noticed in the F_2 families. No attempt was made, however, to obtain counts on these characters. Out of the 484 seeds from F_1 plants, 12 failed to emerge and 9 plants developed smut. There are several factors or combinations of factors which might have prevented the germination of these 12 F_1 seeds, such as mechanical injury caused in dehulling, destruction by insects, or the lethal effect of the smut organism on the young susceptible seedlings. Since it was impossible to determine which factors were responsible, it was decided to analyze the data in two ways; first, by considering the 12 seedlings as susceptible and adding them to the infected class; and, second, by assuming that mechanical or insect injury was the cause of their failure to emerge. Tables 1 and 2 present the results obtained.

TABLE 1.—*F_2 segregation for smut resistance in a Colorado 37 × Markton Cross.**

	No. of plants not infected	No. of plants infected	Total	D/P.E.
Observed...........	463.00	21.00	484	—
Calculated 63:1.....	476.38	7.62	484	7.4
Calculated 15:1.....	453.75	30.25	484	2.6

*The 12 seedlings that failed to emerge were considered as infected.

TABLE 2.—*F_2 segregation for smut resistance in a Colorado 37 × Markton cross.**

	No. of plants not infected	No. of plants infected	Total	D/P.E.
Observed...........	463.00	9.00	472	—
Calculated 63:1.....	464.82	7.18	472	1.0
Calculated 15:1.....	442.50	29.50	472	5.8

*The 12 seedlings that failed to emerge not taken into account.

In Table 1 a very good fit to a calculated 15:1 ratio was obtained and a very poor fit to a calculated 63:1 ratio. In Table 2 just the opposite was true. Due to these conflicting results, no definite conclusion can be drawn from the F_2 data.

Table 3 presents the results obtained by classifying the F_2 plants by use of the F_3 reactions to smut inoculation. Smut counts were made on each row and the rows later grouped into classes according to the percentage infection. A class interval of 5% was used in grouping the F_3 rows. If the data are grouped into two classes, infected and non-infected, it is shown (Table 4) that a good fit to a 9:7 ratio is obtained. Assuming that three independent factor pairs were responsible for resistance, a poor fit to a 27:37 ratio was obtained.

TABLE 3.—*Distribution of F_2 based on F_3 data of the Colorado 37 × Markton cross.*

	Percentage smut arranged in class intervals of 5%																					Total
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
											Colorado 37×Markton											
No.	269	113	38	13	14	5	3	3	1	3	1	–	–	–	–	–	–	–	2	4	3	472
%	57	24	8	3	3	1	0.6	0.6	0.2	0.2	0.2	–	–	–	–	–	–	–	0.2	1.2	0.6	100
											Colorado 37											
No.	–	–	–	–	–	–	–	–	–	–	1	3	1	1	3	4	–	2	–	2	2	19
%	–	–	–	–	–	–	–	–	–	–	5	16	5	5	16	20	–	11	–	11	11	100
											Markton											
No.	19	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	—
%	100	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	—

TABLE 4.—*F_3 segregation for smut resistance in a Colorado 37 × Markton cross and test of goodness of fit to a 27:37 and a 9:7 ratio.**

	No. of plants not infected	No. of plants infected	Total	D/P.E.
Observed...........	269.0	203.0	472	—
Calculated 27:37....	199.5	272.5	472	9.60
Calculated 9:7......	265.5	206.5	472	0.48

*12 F_1 seeds not taken into account.

The results obtained from the F_3 data indicate the presence of two dominant factors for resistance in the Markton parent.

SUMMARY

Markton (C. I. No. 2053), found to be resistant to a mixture of covered smut found at the Colorado State College Experiment Station, was used as the resistant parent. Colorado 37 (C. I. No. 1640), found to be susceptible to a mixture of the same smut, was used as the susceptible parent due to its yielding ability and other desirable characteristics.

The inoculum used was collected from a field of Colorado 37 growing at the Colorado Experiment Station, Fort Collins, Colo. The smut was identified as *Ustilago levis* (K & S) Magn.

All seeds used in the study were dehulled and smutted.

The F_2 results were erratic and no conclusions could be drawn from them without further study.

The F_3 families segregated in the ratio of 9 uninfected to 7 infected. It was concluded that a two-factor difference for smut exists between the parents; Markton possessing the two dominant factors for resistance, while Colorado 37 has the recessive allelomorphs of these factors.

Some very promising, highly resistant lines are being continued in the hope of developing some high-yielding, smut-resistant, commercial strains.

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THE RELATION OF MOISTURE CONTENT AND TIME OF HARVEST TO GERMINATION OF IMMATURE CORN[1]

G. F. SPRAGUE[2]

THE satisfactory and efficient use of the greenhouse in corn breeding and genetic investigation requires that the planting of the winter crop be delayed as long as possible and still permit the maturing of seed before the time of spring planting. Thus, for greenhouse-grown corn, planting usually follows very closely after harvest. Under such conditions corn sometimes exhibits slow and irregular germination. In rare cases a complete failure to germinate is noted. The possibility of poor or irregular germination appeared to be one factor limiting the usefulness of the greenhouse in advancing breeding and genetic investigations.

Under certain conditions small grains have a marked period of dormancy. It was thought that the occasional poor germination of greenhouse-grown corn might be a manifestation of the same phenomenon. These studies were undertaken to determine the importance of after-ripening in corn and, if possible, to find some method of hastening the process.

The germination and subsequent growth of prematurely harvested but thoroughly after-ripened corn has been studied by Robinson[3]. The literature on dormancy and after-ripening has been reviewed by Harrington[4] and no further review will be presented here. For the small grains in general he concludes that the embryo is not dormant, dormancy being imposed by an impermeable seed coat.

MATERIALS AND METHODS

In preliminary comparisons of greenhouse- and field-grown corn there was no evidence of any difference in germination response when corn of equivalent stages of development and maturity was compared. For this reason, all subsequent studies were carried out with field-grown corn since it was more readily available and could be obtained in any desired quantities.

Double and single crosses of field corn have been used to insure greater uniformity and thereby reduce the size of sample necessary for adequate representation. Pollinations for periodic sampling were made on a single day to insure material of known age. Three to five ears were harvested at 5-day intervals beginning 10 days after pollination and continuing until immediate normal germination was obtained. The kernels were removed from the ears immediately after harvest, bulked, and spread in a single layer to dry. Samples for moisture, germination, and chemical treatment were taken from the bulked sample.

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[1]The studies herein reported were conducted cooperatively by the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Missouri Agricultural Experiment Station, Columbia, Mo. Received for publication April 3, 1936.

[2]Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

[3]ROBINSON, J. L. Physiologic factors affecting the germination of seed corn. Iowa Agr. Exp. Sta. Res. Bul. 176. 1934.

[4]HARRINGTON, G. T. Forcing the germination of freshly harvested wheat and other cereals. Jour. Agr. Res., 23:79–97. 1927.

The moisture samples were dried in an electric oven at 100° C. The germination samples were planted in sand and daily records were made of emergence until germination was thought to be complete. No plantings were discarded until germination was perfect or until examination revealed that the ungerminated seeds had rotted.

EXPERIMENTAL RESULTS

The moisture percentage and dry weight per sample of 20 kernels for the periodic harvests are shown graphically in Fig. 1. The summarized data on germination are presented in Table 1. The moisture percentages range from 83.79 for the first harvest to 23.33 for the last harvest. The percentage of germination for these same samples determined immediately after harvest ranged from 0 to 100. Morphological differentiation does not appear to be a factor in these studies since normal plants were obtained from the first harvest sample.

TABLE 1.—*Effect of time of harvest and moisture content on the amount and variability of germination in field corn.*

Days from		Moisture %	Germination %	Days from planting to	
Pollination to harvest	Harvest to sampling			First emergence	Final emergence
10	0	83.79	0	—	—
	4	76.63	5	19	19
	8	50.63	25	6	12
	12	17.35	50	5	7
21	0	67.42	5	11	13
	3	65.86	35	13	21
	8	45.53	90	3	20
	15	16.04	100	3	6
25	0	60.47	20	16	24
	4	45.14	55	6	22
	11	24.24	90	5	7
30	0	48.13	75	6	17
	6	25.73	100	3	8
	8	19.68	100	3	7
36	0	40.59	70	7	21
	2	33.54	100	3	42
	8	17.97	100	4	6
41	0	31.48	85	6	48
	4	26.34	100	3	12
	9	13.29	100	4	6
45	0	29.39	75	6	38
	5	21.69	100	3	6
50	0	27.25	95	4	36
	5	13.76	100	3	6
55	0	23.33	100	3	5

The relationship between the moisture content and the percentage of germination is quite striking both within and between dates of harvest. The percentage of germination increased rather steadily with increasing maturity and decreasing moisture content of the sample. A high moisture content appears to be associated with a high degree of variability in the time required for germination. This relationship is most striking in material harvested 30 or more days after pollination. Presumably a similar relationship exists in the younger material but is partially obscured by the greater incidence of rotted kernels.

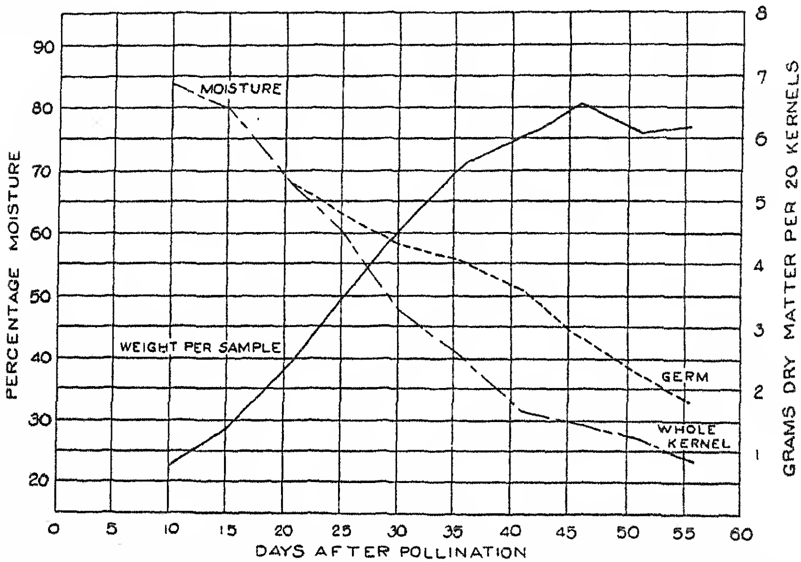

FIG. 1.—Kernel weight and moisture percentage at periodic intervals during development. (Solid and dashed lines represent the whole kernels; dotted lines represents the germs only).

The maximum spread from initial to final emergence for any lot was 42 days. When more completely dried, a second sample from the same harvest dates exhibited a spread in emergence of only 2 days. Tests on thoroughly air-dried and after-ripened corn gave a mean spread in emergence of 2.5 days.

Moisture and germination records on duplicate lots of corn stored in a saturated atmosphere are presented in Table 2. The favorable temperature (80° to 90° F) and the high humidity resulted in such a rapid development of molds that samples could be kept no more than a week. The results indicate, however, that for the short period involved, no appreciable after-ripening occurred. An equal period of storage while exposed to the air was sufficient to produce complete after-ripening. This relationship is very strikingly shown in the 45-day sample in Tables 1 and 2.

The original sample for this date contained 29.39% of moisture, had a germination of 85%, and had a spread of 32 days from initial

to final emergence. After the sample had been allowed to dry for 5 days, the moisture content had decreased to 21.69%, the germination had increased to 100%, and only 3 days elapsed between the emergence of the first and last seedling.

TABLE 2.—*Effect of storage in a saturated atmosphere on the amount and variability of germination in corn.*

Days from		Moisture %	Germination %	Days from planting to	
Pollination to harvest	Harvest to sampling			First emergence	Final emergence
25	0	60.47	55	16	24
	4	61.51	15	7	17
	7	60.96	25	7	10
36	0	40.59	70	7	21
	6	37.62	60	5	15
45	0	29.39	75	6	38
	5	35.89	80	5	46
	10*	16.05	100	4	5

*Removed from saturated atmosphere at the end of 5 days and allowed to air dry for 5 days.

A duplicate lot of the same sample was stored in a nearly saturated atmosphere for 5 days. There was a slight increase in moisture content, from 29.39 to 35.89%, and the variability of germination was slightly increased. When this sample was removed from the saturated atmosphere and allowed to become air dry, the loss in moisture was accompanied by a marked decrease in the variability of the time required for germination.

Various attempts were made to hasten the after-ripening process by means other than drying. Soaking seeds for a 1-hour period in a 1% solution of sodium thiocyanate or a 1.5% solution of hydrogen peroxide was ineffective. The removal of the pericarp and temporary storage under conditions of increased oxygen pressure were also ineffective unless they were accompanied by a loss in water. The results then seem to indicate that there is a strong relationship between the loss of water from immature seeds and their ability to germinate normally.

The data in Tables 1 and 2 indicate that immature samples having more than 25% of moisture will exhibit a reduced percentage of and an increased variability in germination if planted immediately. This is true for all samples, whether freshly harvested or partially dried. This percentage (25) is based on the moisture content for the entire grain. The values for the scutellum and embryo would be somewhat higher as they have a higher moisture content than the endosperm during the later stages of development (Fig. 1).

In view of the relation between the necessary reduction in moisture content and the onset of normal germination in immature corn, it seemed of interest to determine the moisture content necessary for germination.

Starchy and sweet corn seeds were placed, abgerminal side down, on filter paper in a petri dish. The paper was moistened sparingly in the hope that absorption would be so retarded that the seed would germinate when the minimum water requirement had been attained. Seeds were removed from the dish as soon as either the plumule or radicle started to break through the pericarp. They were then separated into embryo and endosperm and moisture percentages determined. The results are presented in Table 3. At the time of germination, the moisture content was higher in the sweet than in the starchy kernels. This difference can be ascribed almost entirely to the endosperm, the moisture content of the two types of embryos being similar.

TABLE 3.—*The moisture content of corn kernels at the time of germination.*

Type of seed	Mean No. of days to germination	Moisture content at time of germination for		
		Endosperm %	Embryo %	Whole kernel %
Starchy......	14.7	31.37 ± 0.26	61.86 ± 0.64	38.02 ± 0.31
Sugary.......	14.6	40.39 ± 0.33	58.34 ± 1.08	45.35 ± 0.35

In a second experiment, a sample of corn was exposed to a saturated atmosphere in a constant-temperature chamber at 23° C. Samples were removed periodically and separated into embryo and endosperm and the moisture content was determined. The experiment was terminated after 49 days. At the end of this period, the endosperm contained 30.7%, the embryo 61.7%, and the entire kernel 35.4% of moisture. The results are presented graphically in Fig. 2. When the experiment was terminated, the kernels were obviously swollen, but the pericarp was still unbroken. The two experiments are in agreement in indicating that the moisture content necessary for germination is approximately 35 and 60% for whole grain and embryo, respectively.

Immature corn having a similar moisture content germinates poorly and is highly variable. This suggests that some irreversible process must occur during drying so that 60% of water in the embryo of after-ripened seeds plays a physiologically different rôle than the same percentage of water in an immature embryo. The nature of the reaction is unknown, but it is subject to genetic variation. Certain genetic types (premature germination, vivipary) germinate on the ear with a high moisture content (60 to 80%). Some variation in time of germination is apparent, but the variability is markedly less than for immature seeds of the same age removed from the ear and planted. It seems plausible that in strains of corn germinating prematurely, some inhibiting mechanism is lost early, functioning only at high moisture contents. In normal corn this mechanism persists until the water content has been reduced below the minimal requirement for germination through the normal process of ripening.

Genetic evidence is available for one viviparous type which indicates the location of the mechanism normally inhibiting germi-

nation at high moisture contents. An undescribed genetic type of maize, found by F. D. Richey and the writer, is characterized by the presence of a pink to salmon coloration in both endosperm and scutellum. This type is recessive to normal and always germinates on the ear. When outcrossed with white endosperm types, in addition to

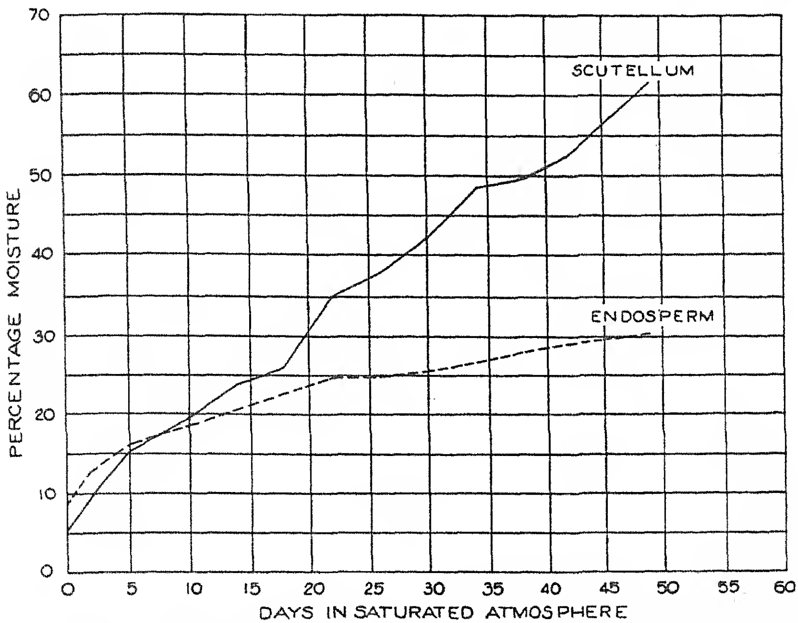

FIG. 2.—The absorption of moisture by corn kernels when stored in a saturated atmosphere.

the expected segregates, two types of hetero-fertilized kernels occurred[5], namely, white endosperm with pink scutellum and pink endosperm with white scutellum. All seeds having pink scutellums, regardless of endosperm color, germinate on the ear. This indicates that the tendency to germinate before dormancy is determined by the scutellum genotype and is independent of the endosperm genotype or of the character of the pericarp. Since the limiting mechanism is hereditary, it must operate in the scutellum rather than in the endosperm.

SUMMARY

After-ripening of immature corn is coincident with the loss of moisture.

Immature corn planted immediately after harvest exhibits great variability in time of germination. With a decrease in moisture content, the percentage of seeds germinating is increased and the variability in time required for complete germination is decreased.

[5]SPRAGUE, G. F. The nature and extent of hetero-fertilization in maize. Genetics, 17:358–368. 1932.

The moisture content of immature seeds must be reduced to approximately 25% before normal germination occurs.

Corn kernels require a minimum of approximately 35 and 60% of moisture in whole grain and embryo, respectively, before germination can occur.

It is suggested that the mechanism which inhibits the normal germination of newly harvested immature corn operates in the scutellum rather than in the endosperm or pericarp.

STUDIES ON HESSIAN FLY INFESTATION AND SOME CHARACTERS OF THE WHEAT CULM[1]

Dean C. Anderson and Hubert M. Brown[2]

A STUDY was begun in 1932 to determine whether there were any significant differences in the amount of Hessian fly, *Phytophaga destructor* Say, injury on the strains of wheats grown on the Michigan Agricultural Experiment Station farm at East Lansing, and, if there were such differences, to determine the relationship between resistance to this fly and breaking strength, weight, diameter of mature culms, and lodging.

Various characteristics of the host plant are said to influence the amount of Hessian fly injury. In brief, these are large coarse straw (7),[3] long ligules which prevent the larvae from reaching the base of the culm and high silica content in cell walls at the base of the plant (3), low ash content in young plants and in mature straw (2), high deposition of cellulose in all walls of crown where larvae begin feeding (4), purple color in straw and genetic characters governing resistance (5), and protoplasmic reaction (6).

MATERIALS AND METHODS

Samples for this study were obtained from the naturally infested wheat nursery by taking a 7-foot section from an outside row of the five-row yield plats from 111 strains of soft winter wheat in 1932 and 112 strains in 1933. Samples from 55 systematically distributed check plats were taken in 1932 and from 52 checks in 1933.

In 1932, 40 to 45 culms from each strain were examined for puparia (flaxseeds). Following the findings of Painter, *et al.* (5), the percentage of infested culms was used as the measure of infestation. Breaking strength, weight, and diameter of culm determinations were made on the center portion of the second internode above the ground. The second internode was used in these determinations because the puparia usually develop on the lower nodes and this internode was of sufficient length to allow the breaking test to be made on it. The diameter of the culm was read from a special V-type caliper and this determination made before further testing. The breaking strength tests were made with the special equipment illustrated in Fig. 1. The force required at the instant of breaking was read from the scale in grams. A 5-cm section of the culm, taken where it had been tested for breaking strength and diameter, was then cut out and weighed on an analytical balance.

In 1933, between 80 and 90 culms from each strain were used in the determinations. Each culm was examined for puparia as in 1932, and those with puparia were placed in one group and those free from puparia in another. Diameter of

[1]Contribution from the Farm Crops Section, Michigan Agricultural Experiment Station, East Lansing, Mich. Journal Article No. 261 (New Series). Received for publication April 18, 1936.

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[3]Figures in parenthesis refer to "Literature Cited," p. 483.

culm measurements were not made on this crop. Instead of one culm, two culms were placed on the scale together and their breaking strength determined. As two culms were broken at a time, individual culm weights were not taken, but

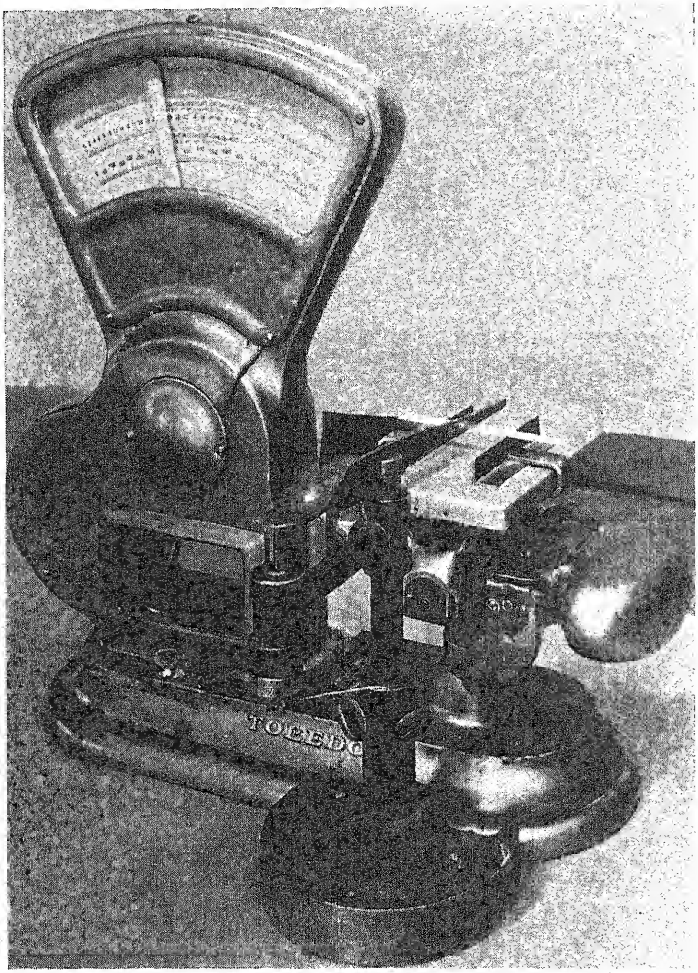

FIG. 1.—Apparatus used in determining the breaking strength of one or two wheat culms at a time. The supports on which the straws were placed were 5 cm apart. The lever arm is caused to press on the straws by a screw adjustment. The point of pressure was midway between the supports. The apparatus was designed by W. H. Sheldon, Dept. of Agr. Engineering, Michigan State College.

the number of culms in and the weight of each of the two groups and those culms with puparia and those free from puparia were recorded to allow for the computation of the average weight per two culms.

The lodging notes taken in 1932 were field observations. Five ratings were used in grading from no lodging to complete lodging. No lodging occurred in 1933.

RESULTS

DIFFERENCES BETWEEN STRAINS

Hessian fly infestation.—The fly infestation in the varieties ranged from 7 to 75% in 1932 and from 5 to 75% in 1933. The same strain was lowest both years and was the only strain that had an average infestation of less than 24%, the next lowest 2-year average. There were four strains that had 60% or more infestation each year. The remaining percentages were fairly normally distributed around the yearly means of 38% in 1932 and 47% in 1933. Standard errors calculated from the check rows indicate that strains which differed from each other in infestation percentage by more than 30% in 1932, 27% in 1933, or 20% for a 2-year average, were significantly different from each other. On this basis, it can be seen that there were decided strain differences in degree of infestation.

Breaking strength of culm.—As breaking strength determinations were made on single culms or pairs of culms, it was possible to obtain strain means and their standard errors for use in determining significance of interstrain differences. A difference between strain averages greater than 50 grams in 1932, when single culms were used, and 80 grams in 1933, when two culms were used, was found to be significant. Strain averages ranged from 199 to 530 grams in 1932 and from 408 to 855 grams in 1933. There were significant differences in the average breaking strength between many of the strains in spite of the fact that individual values of these strains over-lapped. This over-lapping of distributions was due, in all probability, in part to variation in shape of culm cross-section and in part to normal variation and indicated that several readings must be made on each variety to obtain a true value.

Weight of culm.—In 1932, the strain mean weights varied from 29 to 58 mg per straw and in 1933 from 52 to 96 mg. Strains differing by more than 6 mg in 1932 and by more than 12 mg in 1933 were, on the basis of standard errors, considered significant. Several of the strains were shown to differ from each other in weight per culm.

Diameter of culm.—This determination was made only in 1932. Strain means and their standard errors were calculated. These mean diameters varied from 2.3 to 3.9 mm and their standard errors indicated that an average difference of 0.3 mm or greater was significant.

Inter-annual correlations.—It has been pointed out in the preceding discussion that many of the strains differed from each other in regard to percentage of fly infestation, breaking strength, and weight of culm. To determine further whether these significant differences were due to environment or heredity, the inter-annual correlation coefficients were calculated. These were for fly-infestation, .30; for breaking strength, .47; and for weight of culm .54. All coefficients are positive and significant, exceeding the Fisher (1) 1% point, and indicate that heredity was playing a part in the observable differences exhibited by the strains.

RELATIONSHIP OF HESSIAN FLY INFESTATION TO CULM CHARACTERS

The discussion thus far has established the point that the strains exhibited to some extent inherent differences in fly infestation and the three culm characters of breaking strength, weight, and diameter of culm. The relationship of Hessian fly infestation to each of these was then determined by means of the simple (total) correlation coefficients which are as follows:

Percentage of fly infestation with	1932	1933
Breaking strength	—.05	—.08
Weight of culm	—.08	—.18
Diameter of culm	—.01	

These coefficients do not exceed Fisher's (1) 5% points and are so small that they indicate that there was no significant relationship between fly infestation and any of the three culm characters.

The data were also studied to determine the effect of fly infestation within a strain upon the culms that were free from puparia and those that were infested. In nearly every strain the puparia-free group average was higher in breaking strength, weight, and diameter than the corresponding puparia-infested group average. Students' method of interpreting paired results was applied and the analysis showed that differences between determinations made on puparia-free straw and those made on puparia-infested straw were significant.

The consistent significant differences found when comparing group averages of puparia-free and puparia-infested material within the same strain seem to be at variance with the low non-significant coefficients of correlation given above. An explanation of these seemingly contradictory results may be that there is no association from strain to strain between Hessian fly infestation, on the one hand, and breaking strength, culm weight, or culm diameter, on the other hand, but when culms are infested with puparia, the result of such an infestation on the individual culm is such that it becomes, on the average, a weaker, lighter, and smaller culm than does a puparia-free culm of the same strain. This explanation tends to be verified further by the consistency in sign of the coefficients of correlation.

As field lodging notes were arranged in only five classes, the coefficient of contingency was used in determining the relationship of this character to fly infestation. The significance of this coefficient was judged by Fisher's (1) Chi-square test. A significant coefficient .46 was obtained and indicates that the greater the fly infestation, the greater the amount of lodging. The presence of the puparia weakens the stem, thus allowing it to break over more readily than uninfested stems would do.

SUMMARY

Strain determinations on percentage of Hessian fly infestation and field lodging and culm determinations on breaking strength, weight, and diameter were made on 111 strains of soft winter wheat in 1932 and 112 strains in 1933. Differences between strains and the differences between puparia-free and puparia-infested groups within the same strain were studied.

There were significant inter-strain differences in fly infestation, breaking strength, weight of culm, and diameter of culm, and these differences, according to inter-annual correlations, tended to persist from year to year.

There were significant differences in breaking strength, weight, and diameter of culm between the puparia-free and puparia-infested groups within the same strain, but the very low non-significant coefficients of correlation between fly infestation and breaking strength, weight, and diameter of culm indicate that selection for fly resistance by using one of these morphological factors would be ineffective.

Hessian fly infestation and field lodging were significantly and positively associated.

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NOTE

THE USE OF RABBITS IN DETERMINING THE PALATABILITY OR TOXICITY OF FORAGE

AS INDICATORS of what might be expected in more valuable animals, rabbits and other small animals have long been used in studies of diseases, nutrition, and methods of inheritance. Only recently, however, have such animals been used as indicators of the palatability or toxicity of plants.

The study of new plants in a forage nursery not only involves the adaptation of the plant to soil and climatic conditions, botanical relationships, and habits of growth, but also the question of their palatability and toxicity must be answered before conclusions can be drawn concerning their value for forage.

When cattle are used to determine the palatability or toxicity of a plant, it is necessary to have the crop growing on a fairly good-sized plot. This may mean 2 or 3 years delay in obtaining sufficient planting material to make a satisfactory test. In the testing gardens located at experiment stations, hundreds of species and varieties of forage plants are often under observation each year. It would be next to impossible to make a satisfactory test of the palatability of each species represented in such a garden if cattle were used as determiners.

The feed eaten by rabbits is similar to that eaten by cattle and if rabbits can be shown to relish the same kind of plants as cattle, their use in palatability tests would have the following advantages: First, a lower initial cost. Second, their shorter growth period makes it possible to obtain comparable data in much less time. Third, the amount of food required for rabbits is much less than for large animals. The use of rabbits would make it possible, therefore, to obtain preliminary information concerning the toxicity and palatability of a new introduction or of a possible new hybrid within the first year of its growth.

The Florida Agricultural Experiment Station, cooperating with the U. S. Department of Agriculture, has a forage nursery of this type in which several hundred plantings, mostly introductions, are under observation. Many of the plants are of a type that only small quantities of herbage are available any one year, and there is need of a method for testing the palatability and toxicity of these on a small scale.

In the summer of 1931 the Florida Station conducted a palatability test of nine species of crotalaria growing together in one field. Cattle were turned into the field and allowed to graze wherever they wished. The relative palatability of the different species was determined by making daily measurements of the length of rows of each species which had been grazed. Thus it was possible to rank the species in the order of their palatability and to assign a satisfactory score to each. A different lot of cattle was used for each of three periods during the season.

A parallel palatability test was conducted with white New Zealand rabbits on the same species. The crotalaria was cut daily and each species, tied in separate bundles, was placed in individual hutches

where the rabbits had free access to all bundles. The relative palatability of the species was then determined by the amount of material eaten from each bundle. Considerable variation occurred in the ranking of the species as determined by the different lots of cattle and by rabbits. In general, however, the rank as determined by the cattle and the rabbits was very similar.

Hay was made from each of eight species and fed to both cattle and rabbits in a palatability test. The hay for both groups of animals was taken from the same source in order to insure uniformity of the material fed to each animal. The relative palatability of the eight species was determined by ranking them on the basis of the amount of each species contained. With two exceptions the ranking of the species by the cattle and by the rabbits was the same. In each of the two exceptions, the amount of hay consumed was so nearly the same that a slight difference in the consumption of either would have changed the rank.

The results led to the belief that rabbits could be safely used to indicate the palatability of newly introduced plants of which we know little, or nothing. A colony of white New Zealand rabbits was therefore established in connection with the forage crop nurseries at Gainesville, to be used as indicators of the palatability and toxicity of the new plants.

Two methods of feeding the plant material are practiced, namely, hutch feeding and actual grazing of plots. In instances where the plant material was limited, samples of the plant under consideration were cut and placed in the hutch where the animals had access to it. The grazing method has been used when sufficient plant material is available. It is accomplished by the use of small movable pens which are placed over a portion of the plants to be tested and the rabbits allowed to graze at will. Grazing has proved to be more desirable in that the rabbits have a tendency to select their food naturally and there is less danger of forced feeding which tends to interfere with the obtaining of satisfactory information.

A few instances will illustrate that the results from the grazing tests have been very satisfactory. Rabbits when placed on plots of the grass *Arundenella echlonii* refused to graze at first. After they had become hungry they ate it reluctantly. Cattle when placed on a plot in which *A. echlonii* was growing with other grasses left it until the other grasses had been consumed, then grazed it sparingly. Rabbits refused molasses grass (*Melinis minutiflora*) for the first day or two after being placed on a plot, after which time they ate it well. The experiment station at Chinsegut Hill Sanctuary report that cattle ate molasses grass very sparingly at first but after the first few days grazed it readily. Rabbits relished *Pennisetum complanatum*, a coarse grass growing in the nursery garden at Gainesville. The West Florida Experiment Station reports that a bull which had been turned onto a plot growing a mixture of grasses, one of which was *P. complanatum*, grazed this species before eating the other grasses. Rabbits and cattle alike relish the *Digitaria* sp. known as Woolly Finger grass. Similar results have been obtained with other grasses and legumes to which both cattle and rabbits have had access.

"A somewhat limited water-supply, but sufficient for the plant to function properly during blossoming and seed-forming time, is apparently best for alfalfa-seed production." This view has been expressed many times, but previously honeybee tripping activity has not been associated with this type of growth.

TABLE 13.—*Effect of degree of succulency of the field on populations of pollen-gathering honeybees and the tripping activity.*

Type of growth	Number of honeybees per acre		Time examined for tripping	Percentage of blossoms tripped
	Total	Pollen collectors		
Nonsucculent.........	2,400	1,900	2:30 p.m.	26.6
Moderately succulent..	5,800	300	5:00	8.3
Very succulent........	7,200	150	4:00	3.5

No specific data on preference of wild bees for less succulent alfalfa have been obtained, but there are some indications that pollen-collecting wild bees may be less sensitive to succulency than are honeybees.

There was some evidence that flowers freed from thrips and *Lygus* bugs may be more attractive to honeybees. In small plots treated with various insecticides on the Forage Crop Farm at Logan, Utah, by C. J. Sorenson and J. W. Carlson, nectar-collecting honeybees were very abundant, especially in plots treated with DDT. The DDT-treated plants responded with profuse blossoming on unusually long racemes. Data on tripping at 3:30 p. m., August 13, are shown in Table 14, compared with that on other plots where the injurious insects were less well controlled. Tripping in this case could be attributed largely to nectar-collecting honeybees, but it should be added that an insecticide containing pyrethrum definitely repelled honeybees for 2 or 3 days after its application.

TABLE 14.—*Tripping of alfalfa blossoms in adjacent plots treated by three insecticides, Logan, Utah.*

Insecticide	Number of blossoms examined	Percentage of blossoms tripped
Sulfur-pyrethrum..............	999	6.7
Sabadilla......................	879	11.7
DDT:		
3%.........................	1,048	13.5
10%........................	1,061	13.4

SUMMARY

The pollinating insects of alfalfa in Utah were studied during 1943 and 1944 to determine (a) the species of economic importance, (b) their abundance and habits, and (c) the influence of ecological factors on their pollinating activities.

In Utah bees play an essential role in the commercial production of alfalfa seed. Tripping of blossoms occurred, almost without exception, only during the working hours of bees, and as a rule the amount of tripping in the fields was proportional to the number of pollen-collecting visitors. The flower structure of alfalfa is adapted to pollination by insects, and practically no tripping occurred on plants from which bees were excluded.

The production of a 500-pound seed crop per acre, it is estimated, would necessitate the tripping of at least 38 million flowers. In most of the fields observed there was an insufficient number of tripping insects to accomplish that amount of tripping. A scarcity of tripping insects may therefore be an important factor contributing to the present low seed yields.

The flowers producing the alfalfa seed crop in Utah are tripped mainly by the following kinds of bees listed in order of their importance: Pollen-collecting honeybees, *Nomia* or the alkali bee, and *Megachile* or leaf-cutting bees. Honeybees are most valuable to alfalfa tripping in areas where they collect alfalfa pollen; *Nomia* is the leading tripping insect only near its isolated nesting sites; while *Megachile* populations are so widely dispersed that nowhere were they the leading tripping agent, but they aid substantially in the tripping in many localities.

Competitive plants in the environment of alfalfa fields probably determine in large measure where and when bees will work alfalfa for pollen. *Nomia* appeared to prefer white sweetclover; *Megachile* the gumweeds; and honeybees preferred mustards, clovers, thistle, and chicory.

Cultural practices may influence the pollen-collecting activities of honeybees on alfalfa. Honeybees were collecting pollen from fields of nonsucculent, slow-growing alfalfa, while little or no pollen collection was in progress on more succulent fields nearby. Honeybees were working the succulent fields for nectar, but nectar-collecting bees usually trip few alfalfa blossoms. On plots from which DDT had eliminated *Lygus* and thrips, however, alfalfa flowered profusely on very long racemes, and many blossoms were being tripped by nectar-collecting honeybees. Applications of sulfur-pyrethrum appeared to repel bees for 2 or 3 days.

Although honeybees are now the predominant trippers of alfalfa in Utah, seed yields are much lower than when wild bees were depended upon for tripping. Honeybees did not collect pollen from all fields, but only from those growing under conditions where competing pollen sources were at a minimum. Even in favorable areas they appeared to select fields for pollen collection which were in an attractive state of of growth, collecting only nectar from others.

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EXPERIMENTS WITH DDT, SABADILLA, AND PYRETHRUM DUSTS FOR CONTROL OF *LYGUS* SPP. ON SEED ALFALFA[1]

F. V. LIEBERMAN[2]

IN PAST years insecticidal control of *Lygus* spp. on alfalfa grown for seed has been unsuccessful, largely because immediate reinfestation resulting from continual hatching of nymphs and immigration of adults has required several applications of the contact poisons tested and has rendered effective control impractical and prohibitive in cost. In a field plot test of three insecticidal dusts on seed alfalfa during the summer of 1944 at Gandy, Millard County, Utah, DDT (1-trichloro-2, 2-bis (p-chlorophenyl)ethane), one of the two new materials being given preliminary trial, was found to be highly toxic to *Lygus* spp., effective for weeks after application, and definitely promising as a satisfactory control for these bugs.

Since cross-pollination of alfalfa flowers is now considered essential to profitable seed production, this experiment was made at an isolated ranch settlement where alfalfa-visiting wild bees, especially *Nomia melanderi* Ckll., sometimes called the alkali bee, occur in numbers adequate for effective pollination of the crop. In this locality, both *Lygus hesperus* Knight and *L. elisus* Van D. occur, the latter heavily predominating.

Twenty-five plots, 60 feet wide by 145.2 feet long, were laid out side by side in a single row without use of buffer strips. One plot in each consecutive 5 was selected at random for dusting with 10% DDT in pyrophyllite, 10% ground sabadilla seed in a 1:8 mixture of hydrated lime and Georgia talc, 20% ground sabadilla seed in a 1:3 mixture of hydrated lime and Georgia talc, or 10% pyrethrum extract in pyrophyllite (0.2% pyrethrins). The fifth plot was employed as a check. Applications were made with a duster mounted on the rear of a farm tractor and operated off its pulley. Its 22-foot boom was carried at plant-top level and trailed by a 15-foot canvas apron. The tractor was driven lengthwise of the plot three times, each dusted strip being lapped somewhat to assure complete coverage. The speed of the tractor was approximately 3.7 miles per hour. Dusting and all subsequent operations in handling, harvesting, and threshing the crop closely approached actual farm practice. Population counts taken in the plots were based on 25 strokes of a 15-inch insect net.

To avoid repelling or killing alfalfa-visiting bees, the insecticides were applied before many of the plants had produced flowers, or while they were essentially in the prebloom stage. Used at this time none of the insecticides showed repellent effeets on the wild bees. They visited the plots in proportion to intensity of the bloom. No kill of wild bees is believed to have occurred, but mortality would be extremely difficult to observe or determine in the field. No domestic honeybees are present in the Gandy area.

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[2]Associate Entomologist.

Effectiveness of the different treatments in destroying lygus is shown in Table 1. Results of dusting with DDT are based on all five plots treated. Inadvertent irrigation prevented redusting of two plots treated with each of the other insecticides used. Data from these plots are therefore excluded in the presentation. Population data for three check plots are also omitted, because they were affected materially in varying degree by drift from DDT plots adjacent to their south borders. The best-yielding sabadilla and pyrethrum plots were those located next to plots dusted with DDT, which indicates that these plots also were affected by DDT drift. It was impossible, however, to distinguish the effect of the DDT from that of the sabadilla or pyrethrum. The data from these plots have therefore been included without correction for this effect.

Of the two check plots for which data are given in Table 1, the first is highly representative of the unaffected portions of all three check plots omitted. In check plot 2, which had a much lower initial lygus population than any other plot, treated or untreated, the slower increase in population allowed bloom to occur and seed to set before infestation became severe.

DDT was outstandingly successful in accomplishing lygus control because of its ability to remain toxic throughout the period required for flowering and podding of the seed crop. One dusting of the alfalfa

TABLE 1.—*Effectiveness of DDT, sabadilla, and pyrethrum dusts in suppressing lygus populations on alfalfa grown for seed, July-August, 1944.**

Dust	Dosage, lbs. per acre		Stage	Average number of lygus bugs per net stroke					
	First treatment	Second treatment		0†	3†	7† 0‡	9† 2‡	22† 15‡	33† 26‡
DDT, 10%	2.75	None	Nymphs	6.6	0	0	0	0.1	0.1
			Adults	1.6	0.2	0.9	0.6	1.0	0.3
Sabadilla: 20%	29	32.5	Nymphs	5.1	1.2	5.0	1.0	5.3	5.1
			Adults	2.1	0.5	2.3	0.1	2.4	0.8
10%	25	32.5	Nymphs	6.1	1.5	2.9	1.7	5.8	3.9
			Adults	2.1	0.7	1.2	0.2	1.7	1.1
Pyrethrum, 10%§	14	16	Nymphs	8.3	2.6	4.0	3.4	8.2	3.6
			Adults	1.7	1.0	0.8	0.7	2.0	0.8
Checks, untreated: No. 1	None	None	Nymphs	6.1	9.3	9.7	—	6.6	1.7
			Adults	1.3	1.7	1.0	—	0.1	0
No. 2	None	None	Nymphs	2.7	4.1	5.6	—	12.3	5.7
			Adults	2.4	2.8	2.3	0	3.2	0.5

*Treatments applied July 19 and 26.
†Days after first dusting.
‡Days after second dusting.
§Duster failed to deliver this dust at desired dosage of 25 pounds per acre.

growth reduced and held the nymphs to negligible numbers. The sabadilla and pyrethrum dusts gave substantial population reductions, considering concentration and dosage of each, but with rapid hatching of eggs the population of nymphs was speedily rebuilt to menacing strength, and economic destruction of reproductive parts of the plants was resumed. The fact that DDT was much more effective than the other insecticides in killing lygus adults is difficult to appreciate from the data in Table 1. Reinfestation by flight occurred daily in all plots, irrespective of treatment, and was greatest in the more succulent plots. Higher mortality of adults in the DDT plots is indicated by the fact that early morning sweepings yielded fewer adults on these plots than on the others, whereas during the flight period later in the day adult abundance on DDT-treated growth became progressively closer to that on other treated alfalfa. Furthermore, since some adults swept from DDT plots were unable to coordinate leg movements, it was evident that mortality rather than emigration was responsible for their comparative scarcity in these plots in the morning.

Weather may have influenced the effectiveness of all dusts used. No precipitation occurred during the 59-day interval from dusting to cutting of the crop. However, the period was characterized by excessive wind, frequently strong enough to be suspected of removing insecticidal dust.

All treatments were definitely beneficial as measured by the extent of flowering and setting of pods. After the pods had been formed in plots receiving two treatments of 20% sabadilla dust 7 days apart, the appearance of these plots indicated a prospective yield approximately equivalent to that of the plots dusted once with DDT. Lygus feeding on seed in immature pods and the sharply curtailing effect of an early severe frost substantially reduced the promising yields of these plots as well as those of most others. The entire plots were harvested for seed. Results of threshing, recleaning, and examination of seeds from pod samples taken just before frost are given in Table 2.

Yields from plot to plot under the same treatment varied widely. This variation is attributable mainly to a corresponding difference in plant succulency due to variations in soil moisture within the field and intensified by precipitation deficiency. Late in August intensely drying winds reduced yield prospects in all plots, particularly in those already dried to excess. Variation in succulency and also in yield was greatest among the DDT plots. Tardy spot irrigation at various times during the flowering and podding period only added to the variation in plot condition without giving the benefit that timely watering could have provided. Nevertheless, the better yields under each treatment represent those that may be expected under normal seasonal and field conditions.

Without extensive tripping of flowers it would have been impossible to obtain the very high yields realized from the two DDT plots that were only slightly affected by drought and frost. Observations showed that, in proportion to the bloom on the plants, pollinating bees were no more abundant in treated plots than they were on a large adjacent

acreage of blooming alfalfa that was untreated. These high yields were produced under bee activity normal to the locality. They are not theoretical yields achieved by extreme concentration of pollinating insects onto small patches of blooming plants.

TABLE 2.—*Yield and quality of seed from alfalfa field plots dusted with DDT, sabadilla, or pyrethrum in 1944.*

Treatment	Yield, lbs. per acre		Per-cent shrink-age*	Num-ber of seeds exam-ined	Percentage of seed in pod samples				
					Viable		Not viable		
								Destroyed by ‡	
	Thresher-run seed	Recleaned seed			Normal color	Off-color	Imma-ture	Lygus	Chal-cids
DDT, 10%	345 605 725 285 135	322 593 629 264 118	6.6 8.8 13.3† 7.4 12.9†	501 505 504 502 505	81 79 79 58 86	9 16 6 18 6	7 3 11 14 1	3 2 3 9 6	0.3 0.6 0.6 1.2 1.4
Average	428	385	9.8		77	11	7	5	0.8
Sabadilla: 20%	83 343 285	57 283 214	31.1† 17.5 24.9†	453 500 501	63 51 55	15 12 8	10 22 21	12 13 15	0.2 1.8 1.0
Average	237	185	24.5		56	12	18	13	1.0
10%	85 200 183	69 187 146	19.4 6.4 20.3†	249 499 500	57 39 55	14 16 9	12 24 24	16 18 11	0 3.0 1.0
Average	156	134	15.4		50	13	20	15	1.3
Pyrethrum	70 148 115	50 128 89	28.6† 13.6 22.2†	499 106 501	33 40 21	18 12 5	31 22 40	17 26 34	0.2 0 1.0
Average	111	89	21.5		31	12	31	26	0.4
Checks: No. 1 No. 2	 30 260	 23 179	 21.8 31.1†	 8 500	 25 28	 13 7	 25 60	 38 5	 0 0.4
Checks affected by DDT drift	188 310 175	169 285 147	10.0 8.2 16.2†	436 513 500	65 69 46	15 12 12	14 13 18	5 6 21	0.5 0 3.4
Average	224	200	11.5		60	13	15	11	1.3

*Determined from 100- to 300-gram portions of total plot yields. Yield of recleaned seed calculated by use of these percentages.

†Thresher operated with inadequate power; shrinkage was larger than it would have been otherwise.

The cleanliness of thresher-run seed due to the excellent protection of developing pods by DDT is shown by the low shrinkage in recleaning and the small proportion of insect-damaged seed found in pod samples (Table 2). Field observations indicated that the crops in all DDT-treated plots were maturing slightly faster than in the other plots. These observations were confirmed by the smaller percentages of immature seeds found in pod samples as indicated in Table 2. A slight tendency to dry out the alfalfa plants as they neared maturity appeared to be creditable to DDT, but further observations under conditions less influenced by drought and drying winds are needed to decide this point. The remarkable protection given the check plots that received drift of DDT dust indicates that direct application of dosages of this insecticide lower than those used in this experiment will give adequate kill.

The pods from DDT-treated plots contained an average of 4.77 seeds per pod; pods from plots treated twice with 20% sabadilla, 10% sabadilla, or pyrethrum dust contained an average of 2.56, 2.92, and 2.91 seeds, respectively. The lower averages in the sabadilla and pyrethrum treatments were due to the more frequent occurrence of pods with only one or two seeds. Samples from check plots 1 and 2 averaged 1.33 and 3.55 seeds per pod, respectively, the former being representative of the condition that would have prevailed in the treated plots if they had remained untreated. Many pods in these areas contained no seeds at all. In fact, the 8 seeds present in the sample from check plot 1 (Table 2) represent the total production on 25 stems. Check plots affected by drift of DDT averaged 3.06 seeds per pod. Seeds in pods from DDT plots were slightly smaller than those from the check or other treated plots, although no definite relationship to probable casual factors could be established.

A composite sample of recleaned seed from the DDT plots had a commercial purity of 99.25% (premium grade). An official commercial germination test indicated viability to be within normal range for alfalfa seed of this area during the fall season. Quick-germinating seeds averaged 40.75% and hard seeds 53.75% to give a total estimated germination of 94.50%.

Samples of the alfalfa for analysis of DDT residues were taken from treated plots just before and after threshing, 95 to 96 days after the treatment was applied. No rain but much drying wind occurred during the 59-day period between treatment and cutting. Three rains totaling about ¾ inch fell during the 36-day period between cutting and threshing. During this period the alfalfa was in cocks and was turned three times. The analyses indicated that the DDT residues were not over 17 p. p. m. in the alfalfa before threshing and less than 10 p.p.m. in the chaff after threshing. Although these residues exceed the current tentative DDT tolerance of 7 p.p.m., in view of the high degree of lygus control secured in the 1944 tests it seems likely that dosages can be reduced sufficiently to bring the DDT residues within the tolerance and still maintain satisfactory lygus control and economically profitable seed production.

In this experiment, collection of actual data on reduction of insect population was restricted to lygus. However, large aphid and thrips

populations that existed in all plots at the time of dusting were practically eliminated in the DDT-treated plots and slightly reduced in the other treated plots. DDT was also observed to reduce populations (nymphs and adults) of *Nabis ferus* (L.), ladybirds, and grasshoppers. Most of the specimens of these common alfalfa-field insects observed in the DDT plots after they were dusted probably were immigrants.

Further information is needed on the best dosages and mixtures of DDT for use against *Lygus* spp. infesting alfalfa, on timing of applications to avoid the killing of honeybees and other alfalfa-pollinating bees, and on the livestock-poisoning hazard resulting from DDT residues on alfalfa, especially that which may be pastured or cut for hay instead of seed.

INSECTICIDAL CONTROL OF LYGUS BUGS IN ALFALFA SEED PRODUCTION[1]

C. J. SORENSON AND JOHN W. CARLSON[2]

PREVIOUS investigations (1, 3, 4)[3] have demonstrated that lygus bugs constitute a limiting factor in the production of alfalfa seed in Utah and other western states. As a result, various insecticides have been tested at the Utah Agricultural Experiment Station for the control of these insects under field conditions, which, in general, have been ineffective and prohibitive in cost for commercial use. Early in 1944 the new DDT (1–tricholoro–2, 2–bis (p–chlorophenyl)ethane) and sabadilla dusts[4] were made available for testing against lygus in alfalfa seed production.

PROCEDURE AND MATERIALS

The experimental work was conducted at the Forage Crops Station near Logan, Utah. This area is typical of a diversified irrigation farming region in which alfalfa seed was formerly produced with some success, but recently without satisfactory results owing chiefly to severe damage from lygus infestation to alfalfa buds and flowers. Trials were made in 64 plots of Ranger alfalfa, 7×7 feet, arranged in four groups of 16 plots each, which permitted the testing of four insecticides in two dosages, two strengths, and four replications.

Hills (2) found in insecticidal tests during 1943 against lygus in sugar beet seed production that, "pyrethrin-sulfur dust (a pyrethrum extract-impregnated dust containing 0.2% pyrethrins and 50% sulfur)" gave best control of lygus infestation. Inasmuch as this material had not been used in previous control studies of lygus in alfalfa seed production, it was included in the 1944 tests. The present study includes, therefore, the following four insecticides: (a) Sulfur-Pyrocide mixture, composed of dry Pyrocide (10% strength, containing 0.2% pyrethrins) 10 pounds, pyrophyllite 40 pounds, and sulfur 50 pounds; (b) sabadilla, 10%; (c) DDT, 3%; and (d) DDT, 10%. The Pyrocide used had been left over from work done in 1942 and may have been of inferior quality, owing to age and deterioration in storage.

FIELD TECHNIQUE AND METHODS

The experiment was planned primarily for testing the relative efficiency of DDT and sabadilla dusts in comparison with Pyrocide, which previously has been considered to be the most effective insecticide known for the control of lygus in alfalfa seed production. Check plots receiving no treatments appeared in the light of previous experiments to be unnecessary for an efficient evaluation of the new dusts. Plots receiving different treatment were separated by cultivated alleyways 8 feet wide. Each group of 16 plots comprising a replication were in turn separated by alleyways 12 feet wide. The alleyways were intended to lessen to some extent the effects of drift when applying the insecticides and to reduce migration of bugs between plots receiving different treatments. Replication D was more closely adjacent to other untreated alfalfa that was being cut regularly in

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[3]Figures in parenthesis refer to "Literature Cited", p. 500.

[4]DDT in 5% strength was supplied by the Geigy Company, Inc., New York City, and in 10% strength by the Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture. Sabadilla dust in 10% strength was furnished for the test by the McConnon Company, Winona, Minn.

a forage yield study than were the other plots. It was therefore directly exposed to damage resulting from re-infestation at regular intervals during flowering and seed setting. A statistical analysis of lygus populations and seed yields for the various plots was made, as shown in the following tables, and a statistical evaluation of the effects of the various treatments has also been attempted.

APPLICATION OF INSECTICIDES

Separate hand dusters of the rotary type were used for each of the four insecticides. Two cloth cages of a size large enough to cover an entire plot were placed over the alfalfa during application to reduce drift (Fig. 1). One cage was left in position over a plot for several minutes while application was being made under the second cage in position over another plot. A removable section of the top of each cage, approximately 18 inches wide, facilitated application of the dusts within the cages. Application began on July 18 and continued to September 9.

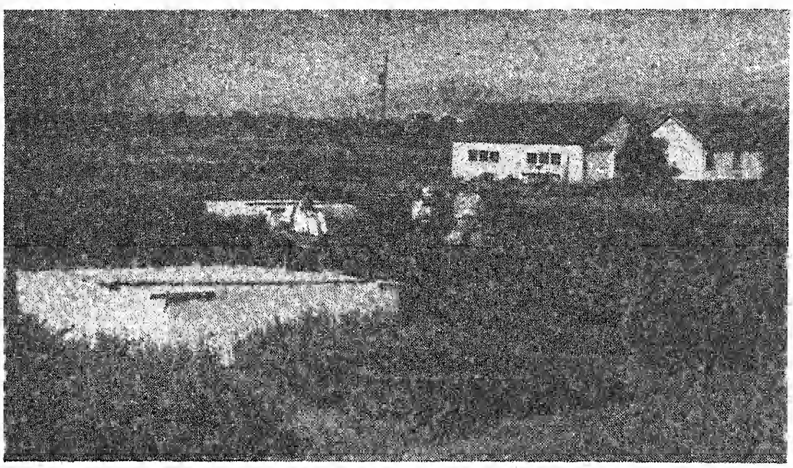

FIG. 1.—Showing type of plots and cages used in the insecticidal control of lygus infestation in alfalfa seed production, Forage Crops Station, Utah Agricultural Experiment Station, Logan, Utah.

Dosage used.—Each insecticide was used at the rate of 30 and 50 pounds per acre on respective plots in each replication. These amounts, although thought from the outset to be excessive, were used because application of smaller measured quantities on separate plots proved to be impractical.

Frequency of application.—Previous experiments for insecticidal control of *Lygus* in alfalfa seed production had shown the lygus population to build up to injurious proportions on small experimental plots through migration from surrounding host plants within four or five days following treatment. It was planned, therefore, to repeat the application of insecticides in 1944, at weekly and semiweekly intervals on respective plots in each replication. This plan was carried out from July 18 to August 15. From July 18 to August 8, it was shown by frequent counts that the lygus population on the treated plots was being held to a relatively low number in comparison with that on untreated alfalfa. Following the cutting of the second crop on nearby fields on August 6, a heavy influx of adult *Lygus* to the experimental plots occurred. Application of treatments two days later on August 8 again reduced the bug population on the plots to approximately the same low level as it had been before migration.

Because of the continued low population of lygus on DDT-treated plots following the applications of August 8, further treatment was withheld until August 22, when the population was again approaching damaging numbers. The plots

were therefore again given their respective treatments, which for the DDT was the last for the season, whereas regular applications of sulfur-Pyrocide and sabadilla were continued to and including September 9. Because of this change in the original plan for frequency of application, the plots which were to have received weekly treatment with DDT received 5 instead of 9 applications, and those which were to have been dusted semi-weekly with DDT received 9 instead of 16 treatments.

Lygus numbers for each of the 64 plots were determined by the sweep method, taking four strokes of the insect net through the alfalfa, immediately before applying the insecticides and again 24 hours thereafter. In order to study the reactions of lygus to the effects of the respective insecticides, from 10 to 20 adults or nymphs were collected from nearby untreated alfalfa plots and placed in separate wire-screen, cylindrical cages, 12 × 16 inches. The cages were placed in the alfalfa of the various plots immediately prior to applying the insecticides. Observations on the effects of the treatments on the bugs were made at intervals of 10, 30, 60, and 180 minutes after applications.

RESULTS

Results obtained from the application of the insecticides are given in Table 1. Comparisons based on a statistical analysis of the data show highly significant differences between the means of treatments for lygus populations and seed yields. The inferior control of lygus infestation obtained with sulfur-Pyrocide is probably attributable to the poor quality of the material used, while otherwise the generally satisfactory control shown for DDT and sabadilla affords encouragement for the possibly greater use of insecticides as an aid in the production of alfalfa seed.

DDT, 10%, gave the best control of lygus and the highest average yields of seed in the test. DDT, 3%, was second best with sabadilla, 10%, third, although differences between the latter two are statistically insignificant. Covariance analysis shows a statistically significant general negative correlation ($r - 0.630$) between lygus population and seed yields of the 64 plots. In other words, high lygus populations are shown to be consistently associated with low seed yields and *vice versa*. About 40% of the total variance between seed yields is thus accounted for by differences between the lygus populations of the plots, as is apparent from the magnitude of the correlation coefficient for totals.

Evidence of the importance of lygus infestation is shown also by consistently lower seed yields for plots exposed to heavier and more frequent infestation because of location. As stated previously, the plots of replication D were in close proximity to untreated alfalfa that was being cut for the production of hay. As a result, these plots became more heavily infested through migration, particularly immediately following the cutting of the various hay crops. Plots of replication C were similarly affected because of their location, although not to the same degree. Differences are apparent in that plots of replications C and D thus in proximity to an outside source of infestation show a higher lygus population than do those of replications A and B that were farther away. While the differences in lygus population are statistically significant, and those of the seed yields are not, a general consistency is apparent in the relationship; the seed yields of replication D being consistently lower than those of A and B for all insecticidal treatments. High negative correlation coefficients ($r -0.943$ and

TABLE 1.—*Mean number of lygus captured per plot with four sweeps of insect net with 19 samplings during the season and yields of seed in pounds per acre in relation to insecticidal treatments in four replications near Logan, Utah, 1944.*

Insecticidal treatment	Replications								Means		Relative %	
	A		B		C		D					
	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.
Sulfur-Pyrocide...	171	147	128	121	174	127	180	105	163	125	199	38
Sabadilla, 10%....	118	245	119	251	165	274	148	180	137	237	167	71
DDT, 3%........	103	248	85	323	116	187	125	212	107	242	130	73
DDT, 10%.......	76	388	68	340	88	319	95	302	82	332	100	100
Means: *Lygus*.....	117		100		136		137		122		149	
Seed......		257		260		218		204		234		70
Differences required for significance:												
Between means of treatments												
5% point									16	60		
1% point									23	86		
Between means of replications												
5% point									23	—		
1% point									42	—		

Statistical Analysis

Sources of variation	Mean square			Correlation	
	DF	Lygus	Seed	DF	Coefficient (r)
Between means of treatments.......	3	20,069**	115,340**	2	−0.943
Between the means of replications...	3	4,943**	12,254	2	−0.912
Treatment × replication (error 1)....	9	413	5,685		
Remainder†.................	48	1,013	2,358	56	−0.215
Total......................	63			62	−0.630**

**Statistically significant at 1% point.

†The statistical significance of the remainder components was determined by appropriate analysis and constitutes the basis for the conclusions drawn with respect to effects of frequency of application and dosage.

r −0.912) for between lygus numbers and seed yields for means of treatments and for means of replications, respectively, are shown that closely approach statistical significance at the 5% level. The degrees of freedom, however, are too limited for a satisfactory estimation of r in these comparisons. With the effects of replication and treatment removed from the total variance, low and statistically insignificant correlation (r −0.215) between lygus population and seed yields is shown for the remainder (Table 1).

FREQUENCY OF APPLICATION AND DOSAGE

Differences between the means of lygus populations and seed yields for weekly and semi-weekly applications of the insecticide are shown in Table 2 to be statistically significant. Similar differences between the means of dosages of 30 and 50 pounds, respectively, were shown by analysis to be insignificant. A study of interaction effects between treatments and dosages shows the heavier application of sabadilla to be more effective, which is indication that this insecticide might have been tested at less than optimum strength and quantity for best results. The efficiency of the sulfur-Pyrocide was low in all combinations of strength and dosage, whereas DDT was relatively efficient. It seems, therefore, that DDT may possibly have been used in a strength and dosage higher than would have been necessary for good results.

TABLE 2.—*Mean number of lygus per plot and yields of seed in pounds per acre in relation to frequencies of application of insecticides near Logan, Utah, 1944.*

Insecticidal treatment	Weekly		Semi-weekly		Means	
	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.	Lygus, No.	Seed, lbs.
Sulfur-Pyrocide	156	119	171	131	163	125
Sabadilla, 10%	159	200	115	275	137	237
DDT, 3%	117	209	97	276	107	242
DDT, 10%	99	302	65	363	82	332
Means: *Lygus*	133		112		122	
Seed		207		261		234
Difference required for significance:						
Between means of frequencies of application						
5% point					11.04	36.68
1% point					14.81	49.22

BIOLOGICAL RELATIONSHIPS

Although no significant difference was noted in the effects of the various insecticides upon lygus bugs within the small wire-screen cages, sabadilla dust appeared to be more irritating and killed them quicker than the other insecticides. Nymphal bugs within the cages appeared to be somewhat more resistant to all the insecticides than were adults. One hour after treatment, approximately 33% of all bugs were dead and after 3 hours usually all the bugs were dead.

After treatment of the experimental plots had been started, practically no lygus nymphs were captured on those treated with DDT, indicating that either oviposition had not occurred on them, or if it had, the newly hatched nymphs failed to develop; also, that reinfestation by adults resulted from their migration from untreated alfalfa and/or other nearby host plants.

On the DDT-treated plots, it was observed that the thrips population was negligibly low; whereas, on untreated alfalfa, particularly during the blossom period, these insects were exceedingly abundant.

SUMMARY

Early in 1944, the new DDT and sabadilla dusts were made available for testing against lygus in alfalfa seed production. Trials were made in 64 plots arranged in four groups of 16 plots each, which permitted the testing of four insecticides in two dosages, two strengths, two lengths of time between applications, and in four replications. The experiment was planned primarily for comparing the relative efficiency of DDT and sabadilla with Pyrocide, which previously had been the most effective known insecticide for the control of lygus infestation in alfalfa seed production. Separate hand dusters of the rotary type were used for each of the four insecticides. Two cloth cages, of a size large enough to cover an entire plot, were placed over the alfalfa during application to reduce drift.

The results show highly significant differences between the effects of the various insecticides. The inferior results obtained with Pyrocide are attributed to the poor quality of the material used, while otherwise the generally satisfactory control of the lygus infestation with DDT and sabadilla offers encouragement for the possibly greater use of insecticides as an aid in the production of alfalfa seed.

A complete statistical analysis of the lygus populations and the seed yields for the various plots was made, the relationship between the lygus populations and the seed yields being evaluated by the covariance method. High lygus populations in the plots were shown to be consistently associated with low yields of seed and *vice versa*, the covariance analysis showing a statistically significant negative general correlation coefficient ($r -0.630$) between lygus population and seed yields of the 64 plots. With the effects owing to treatment and replication removed from the total variance, the low and statistically insignificant correlation ($r -0.215$) is obtained for the remainder.

Differences are shown for weekly and semi-weekly applications of the insecticides. Differences due to dosage, however, were insignificant. The efficiency of sulfur-Pyrocide was low in all combinations of strength and dosage, whereas DDT was relatively efficient.

One hour after treatment approximately 33% of all bugs in the small screen cages were dead and after 3 hours usually all bugs were dead. Sabadilla dust appeared to be more irritating and killed lygus quicker than the other insecticides. After treatment with DDT practically no lygus nymphs were captured. It was observed also that the thrips population was negligibly low on treated plots, whereas in untreated alfalfa these insects are exceedingly abundant.

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POLLINATION, LYGUS INFESTATION, GENOTYPE, AND SIZE OF PLANTS AS AFFECTING SEED SETTING AND SEED PRODUCTION IN ALFALFA[1]

JOHN W. CARLSON[2]

PRACTICAL growers of alfalfa seed have found from experience that high yields and profitable crops may sometimes result independently of any prescribed field practices. It is generally recognized, however, that the weather must be right and that pollination of the flowers is essential to seed setting and production. The general effects of soil types and timely irrigation on the growth of alfalfa have frequently been regarded as factors to be reckoned with in the production of seed; and to western growers has come also an appreciation of the importance of lygus bug infestation. These early empirical concepts have now been greatly modified as a result of recent investigation that has directed attention to pollinating insects and to control of lygus bugs with newly discovered insecticides.

PRELIMINARY STUDIES

Preliminary studies of pollination as affecting seed setting and production in alfalfa were made at the Forage Crops Farm, Utah Agricultural Experiment Station, in 1941. Four seedlings each of four varieties were entered that year into a field plot for observation of seed setting in relation to self and cross pollination. Late buds and fully opened untripped flowers of five racemes of each plant were counted and enclosed in a paper bag for seed setting with self-pollination. The flowers were not manipulated artificially, either prior to or after enclosure in the bags, and seed setting was effected without assistance and stimulation. Untripped fully opened flowers of a second similar group of five racemes were artificially tripped and cross-pollinated, using pollen from an unrelated plant. Tripping was effected in a manner such that the stigma would strike directly upon the pollen mass of a flower held in position for cross-pollination. Trials were repeated at 15-day intervals five times during the season, once in July and twice each in August and September. Counts were made of more than 7,000 flowers, for which the percentage of pods formed is given in Table 1. The data are of interest mainly in showing wide variation in seed setting for individual plants of alfalfa.

SEED SETTING WITH SELF-POLLINATION

An increase in seed setting with self-pollination sometimes occurs with wide fluctuations in day and night temperatures, as is indicated in the behavior of plants Nos. 3, 4, 5, and 6 (Table 1) during the September periods of observation, a phenomenon which appears to be associated with conditions favoring automatic tripping and self pol-

[1]Contribution by the Division of Forage Crops and Diseases, Agricultural Research Administration, U. S. Dept. of Agriculture, and the Utah Agricultural Experiment Station, Logan, Utah. Received for publication December 21, 1945.
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TABLE 1.—*Variation in seed setting in 16 plants of alfalfa with self-pollination and cross-pollination for five 15-day periods of the flowering season at Logan, Utah, 1941.*

Plant No.	Periods of flowering and percentage of flowers forming pods									
	July 14–31		Aug. 1–15		Aug. 16–31		Sept. 1–15		Sept. 16–30	
	Self	Cross	Self	Cross	Self	Cross	Self	Cross	Self	Cross
1	1.5	36.4	5.1	33.3	5.9	29.5	5.1	43.3	4.3	22.5
2	1.3	51.9	3.3	37.5	5.8	38.8	14.2	72.4	—*	—*
3	4.1	61.7	0.0	76.3	1.1	84.6	12.5	97.7	24.4	50.0
4	4.2	43.6	1.7	51.6	2.0	40.3	12.5	33.5	22.8	86.3
5	3.0	10.0	0.0	10.5	1.2	5.8	5.0	40.0	31.2	11.7
6	0.0	27.2	3.8	51.0	7.1	48.9	14.2	31.1	15.3	52.6
7	9.9	85.2	14.0	83.3	17.9	87.8	14.8	86.8	15.7	68.7
8	1.2	38.7	9.3	33.3	4.6	50.0	6.0	54.2	0.0	46.8
9	1.7	71.1	0.0	27.2	1.5	76.7	20.6	53.1	4.3	39.1
10	1.4	75.0	25.4	56.5	4.9	60.0	4.3	72.2	5.4	48.1
11	3.0	36.3	0.0	28.3	25.0	52.7	1.7	33.3	8.6	45.8
12	3.8	16.7	0.0	10.6	0.0	15.0	0.0	14.2	0.0	6.8
13	12.2	40.5	0.0	26.9	9.5	38.7	4.4	31.1	6.9	45.7
14	20.0	80.5	34.7	72.1	19.5	57.7	69.7	75.0	25.7	68.9
15	6.4	69.7	3.4	71.4	2.1	62.1	7.2	54.2	0.0	53.8
16	0.0	81.1	10.5	64.3	6.1	89.4	10.2	76.1	17.5	88.0
Mean	4.6	51.6	6.9	45.9	7.1	52.4	12.6	54.3	12.1	49.0

*No data.

lination. A distinctive type of seed pod development may also be noted at the same time as a result of pollination in some flowers prior to tripping. Fertilized and enlarging pistils may be seen protruding or "growing out" from the apex of the keel, which condition is indicative of pod growth and development resulting from self pollination. The rate of petal wilting in self-pollinated flowers is likewise distinctive. General wilting which results in complete collapse of petals and pistils is usually indicative of a lack of pollination and fertilization, while gradual wilting, which in the initial stages is limited to the edges of the standard petal, is suggestive of seed setting with self-pollination, or cross-pollination prior to tripping. Evidence of seed setting in gradually wilting untripped flowers was obtained from specimens examined histologically, 13 flowers of a total of 84 examined being shown to have well-developed pollen tubes or embryos. The ovaries of partially wilted self-fertilized flowers are usually firm and hard in comparison with those not setting seed and showing general wilting. As a rule, the percentage of flowers forming seed pods with self pollination and without prior tripping is not high, but it is known to occur and to vary widely with individual plants under different environmental conditions.

TRIPPING AND CROSS-POLLINATION

The structure of the alfalfa flower is an adaptation favoring seed setting with tripping and cross-pollination. Beneficial effects of

tripping are indicated from the results of early investigations of alfalfa seed setting, as shown in the writings of Piper, *et al.* (13),[3] Frandsen (9), Hay (11), Southworth (15), and Carlson (3). The superior potency of foreign pollen in fertilization is shown also in the work of Piper, *et al.* (13), Cooper, Brink, and Albrecht (5) and others. Tripping as a means of effecting contact between the stigma and pollen with self-pollination was shown by Armstrong and White (1). Hadfield and Calder (10) and Tysdal (17) concluded later that alfalfa flowers must be tripped to produce seed, and they show the importance of pollinating insects in relation to seed setting and seed production.

Emphasis is given to honeybees in alfalfa seed production by Dwyer and Allman (7) who report tripping up to 64.71% of the flowers visited. Torssell (16) concluded that tripping is a fundamental condition for seed setting in Sweden, although low-tripping frequency was not considered to be the important limiting factor in seed setting under the humid conditions of that country. Knowles (12) states that occasional plants of alfalfa set seed well without insect visitation because of a high degree of automatic tripping and partial self fertility. He found marked variation among plants of Grimm alfalfa in tripping and pod setting behavior. Temperature was regarded by him as the most important of the weather factors influencing the tripping of alfalfa flowers. Significant correlations were found between the amounts of tripping, the amounts of seed setting, and the abundance of leaf cutter or Megachile bees. Cooper, Brink, and Albrecht (5) show alfalfa to be partially self-incompatible and collapse of fertile ovules to be significant as a factor in successful seed setting.

EXPERIMENTAL PROCEDURE

SITES

Three sites were selected in 1944 for a further study of pollination in alfalfa. One was at the Forage Crops Farm, Utah Agricultural Experiment Station, near Logan. It is typical of a diversified irrigation farming area in which alfalfa seed was formerly produced with some success. Another was located about 8 miles from Logan in a sub-irrigated dry land region that has been used for more than 60 years in the production of dry land wheat and alfalfa. The production of alfalfa seed in this region has declined markedly in recent years, such that it is now being shifted farther back into the hills onto virgin alfalfa land, as illustrated in Fig. 1. The native flora of virgin areas seems to offer conditions favoring an abundance of wild bee pollinators of alfalfa flowers and a minimum of lygus bugs and other insects harmful to the production of seed. The third site of the investigations was located in an isolated virgin area of the dry land region and is referred to as the isolated hill plots.

The soils at all sites are of good depth and texture, although maximum production of seed is often limited by a deficiency of soil moisture in the dry land region after midsummer. Lygus infestation and poor pollination under irrigation seem also to limit the production of seed despite satisfactory growth and flowering by the plants. The hazards besetting the production of alfalfa seed in Utah and other western states are thus shown to be numerous and often beyond control.

MATERIALS

Of the 16 plants included in the first study of pollination and seed setting, three were selected as seeming to merit attention in a second trial, namely, Utah Grimm No. 12, Utah Grimm No. 14, and Utah Ranger No. 7, which were chosen for char-

[3]Figures in parenthesis refer to "Literature Cited", p. 513.

acteristic response and as being representative of a wide range of types in seed setting behavior. Plants having outstanding characters were obtained also from other sources. One having red roots was procured from R. A. Brink, Wisconsin Agricultural Experiment Station, to be used as an indicator of natural crossing under field conditions. The original red-rooted plant in crosses with ordinary alfalfa gave ratios of about 3 red and 1 white. Since this genotype does not produce all red-rooted plants when crossed with normal, it has been of only limited usefulness as a tester for natural crossing. Other genotypes were obtained from H. M. Tysdal, Nebraska Agricultural Experiment Station, and the Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.

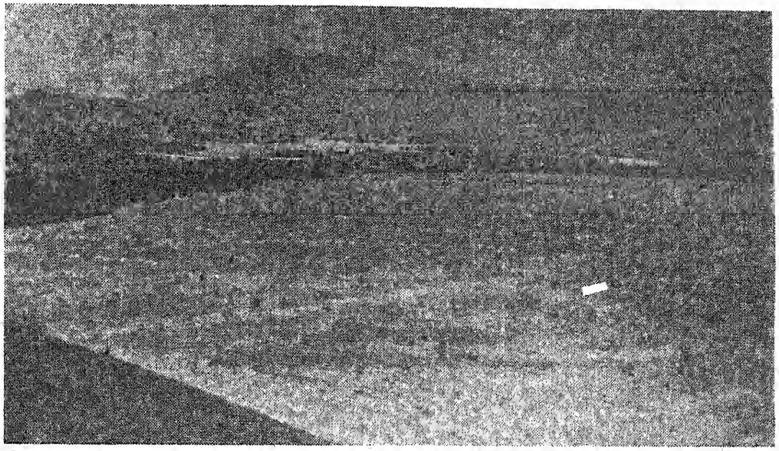

FIG. 1.—Area typical of the dry land region in which the isolated hill plots used in the pollination studies are located. Dry land wheat recently cut is shown in the foreground. The site of the isolated hill plot is shown in the upper left hand corner of the picture.

Nebraska 1226 is a selection made after repeated hybridization, whose pedigree can be followed through several outstanding hybrid progenies. It has been shown to be relatively self-sterile and highly variable in seed production under the conditions of the present test. Nebraska 1255 is a selection from a cross between two selected open-pollinated plants that seems to be highly productive of seed. Its flowers appear also to be preferred by visiting bees as a source of pollen and nectar. The genotype Nebraska 1101 has an odd leaf character that is inherited as a recessive, and is therefore of value as an indicator of natural crossing.

METHODS

Clonal progenies of the seven alfalfa types were grown in the greenhouse in the spring of 1944 and later transplanted to the field. One plant each of six clonal lines was set as a group 18 inches apart in a random order. Plants of the red-rooted remaining clone were then placed around the group of six plants as a source of foreign pollen for a study of the effects of cross pollination. Plantings of the six clones were distributed at random in 10 replications within two closely adjacent plots or blocks for differential treatment at each of three sites.

Treatments were planned to study insect pollination and lygus infestation as possible limiting factors in seed setting and production under Utah conditions. The replicated plantings of one plot at the dry land sites were enclosed in a large cloth cage built for the exclusion of pollinating insects, as illustrated in Fig. 2, while the remaining plot of the pair at these sites was left exposed for seed setting with open pollination. Treatment in the irrigated region was designed to determine the effects of lygus infestation in relation to the production of alfalfa seed. Application of pyrethrum dust was made twice weekly to the plants of one plot during the

period of flowering, while plants of the other plot were left untreated and exposed to the natural infestation of the area. Lygus infestation at the dry land sites was low and did not require regular application of the insecticide, although occasional treatment was given to insure protection from possible damage by this harmful insect.

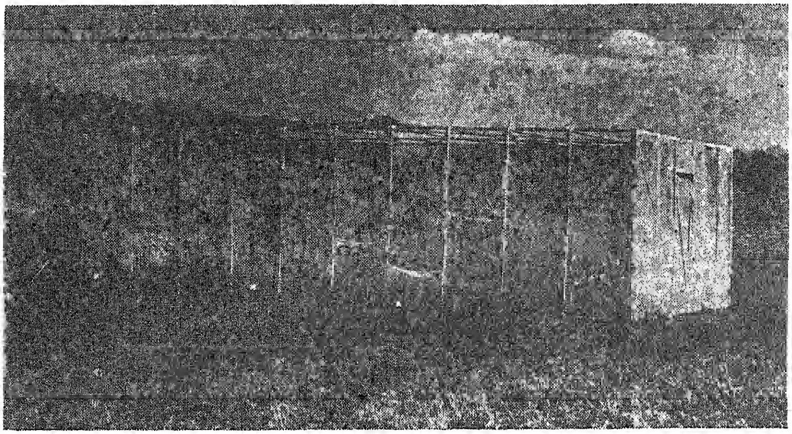

FIG. 2.—The type of cage used to exclude pollination insects from the alfalfa plants. (Isolated hill plots dry land region, 1944.)

Plants of two replications of each plot constituted the source of flowers for detailed studies of pollination. Methods of flower study were similar to those described previously, although observations were limited to three flowering periods of the season instead of five; however, plants of all replications were harvested individually and placed in paper bags for drying. Seed and forage yields are reported in grams per plant, forage yields being on a moisture-free basis less the weight of the seed. Seed yields are reported directly in grams per plant on a recleaned basis, and are also calculated to pounds per acre for a practical evaluation of the results.

RESULTS

POLLINATION AND GENOTYPE

Table 2 summarizes the pollination data and seed yields of the six clones at the three sites of the investigation. In column 1, seed setting with self pollination is found to range from 1.8 to 34.0%. The self fertility of the genotype Utah Grimm No. 14, which in the preliminary study of pollination (Table 1) was 33.9%, is shown in this second trial and under widely different conditions, to be approximately the same. Since hybrid seed gives rise to more vigorous progenies than selfed seed, low self fertility in the majority of alfalfa plants seems desirable as assurance that seed setting will result largely from cross pollination. The first four of the six clones, listed in Table 2, are thus low in seed setting with self pollination, a condition which, with one exception, is accounted for by lack of tripping. The exception is that of the self-sterile genotype No. 2 (Utah Grimm No. 12) in which poor seed setting seems not to be attributable to a lack of tripping, as indicated by a low percentage of flowers (8.8) forming pods with artificial tripping. Low efficiency of seed setting was first

noted for the parental plant of this clone in the initial study of pollination (0.0 to 3.8%, Table 1), and general sterility is assumed. In the absence of cross pollination, maximum seed setting is obtained with self pollination stimulated by artificial tripping, as shown from data given in column 2 (Table 2). The range from 8.8 to 56.5% with tripping is unrelated to the range for self pollination without tripping, as given in column 1. Data for cross pollination appear in column 3 (Table 2). These data show a general consistency with those of column 2, with the exception of the self-fertile genotype No. 6, in which the gain attributable to cross pollination is not marked owing to a high level of self fertility. Seed setting with self pollination and tripping in this clone (52.7%) is essentially as high as for cross pollination (58.1%). Because of the high potency of its own pollen, no doubt some self fertilization occurred when cross fertilization was intended. Lack of tripping, rather than impotency of the native pollen, in the remaining clones seems to constitute the main cause of poor seed setting with self pollination.

TABLE 2.—*The average seed yields based on approximately 30 clonal plants each of six genotypes in relation to the percentage of sample flowers forming seed pods with self pollination, cross pollination, and open pollination at three sites of the investigation, first season clonal plants, 1944.*

Genotype		Self pollination		Cross pollination	Open pollination	Calculated (app.) yield per acre of seed, lbs.*
No.	Source	Without tripping	Stimulated by tripping			
		1	2	3	4	5
1	Nebraska 1226	5.2	28.2	60.5	18.0	139
2	Utah Grimm No. 12	3.9	8.8	34.6	22.5	37
3	Nebraska 1255	1.8	46.7	70.2	39.8	273
4	Utah Ranger No. 7	6.3	56.5	90.7	27.0	441
5	Nebraska 1101	17.1	40.8	73.9	32.2	112
6	Utah Grimm No. 14	34.0	52.7	58.1	53.5	192
Means		11.3	38.9	64.7	32.2	199
Total flowers		1,359	1,728	1,184	915	

*Based on the area occupied by each plant (42.8 pounds of seed per acre per 1 gram of seed) n = 30.

The fifth column of Table 2 presents the mean seed yields per acre with open pollination at the three sites, based on the area occupied by each plant. The range is great, although the yields correspond rather closely to the percentage of flowers forming seed pods with self pollination stimulated by artificial tripping. An exception is again encountered for the genotype No. 6 in which seed setting with self pollination is relatively efficient, while the seed yields are comparatively low. Lower yields with self pollination might be expected since mortality among self-fertilized embryos is known to be generally higher than for cross-fertilized embryos, as shown in the work of Cooper, Brink, and Albrecht (5) previously cited.

The data presented in Table 2 suggest a relationship of possible significance, namely, that the potential seed setting capacity of individual plants and genotypes of alfalfa seems to be closely associated with a particular response to controlled pollination. The effects of cross pollination especially appear to afford a good index for an estimation of seed setting potentials, although self pollination stimulated by trippings seems also to have predictive value for the reason that tripping is an essential condition for highly efficient pollination. The data also show the importance of differences between individual plants and genotypes of alfalfa in relation to the production of seed.

Close agreement between the percentage of flowers forming seed pods with open pollination and the actual seed yields is not apparent with the same consistency as was shown for self pollination and cross pollination with artificial tripping. Reasons may be cited as follows: (a) Seed setting with open pollination is largely a chance effect resulting in some flowers from self pollination and in others from cross pollination, the latter being dependent upon chance visitation by wild bees and honeybees to alfalfa fields during the period of flowering; (b) adequate sampling as a basis for a determination of seed setting with open pollination requires that a prohibitively large number of flowers be examined for evidence of tripping and pollination, which, for practical reasons, is not usually attempted.Regardless of the type of pollination, seed yields are influenced by others factors as well, such that efficiency of seed setting is not always a reliable index of seed yields, the size of the plants and the number of flowers being factors of importance and direct significance.

POLLINATION AND SEED PRODUCTION

As stated previously, the clonal plants of one plot at each of the dry land sites were enclosed in large cloth cages (Fig. 2) for the exclusion of wild bees and honeybees during the period of flowering and seed setting, while those of the closely adjacent plot were left exposed to insect visitation as checks. The results are given in Table 3, and the average percentage of flowers forming seed pods with selfing, open pollination, and cross pollination are shown for the two conditions. After adjustment for size of the plants, as given in column 7, Table 3, the highest seed yields are shown for plants at the isolated hill plots where insect pollination was most efficient. An adjusted yield of 315 pounds of seed per acre is shown for 39.4% of the sample flowers under observation forming seed pods with open pollination, as compared with 228 pounds in the sub-irrigated area where 33.9% of the observed flowers formed pods. Seed setting efficiency with artificial cross pollination shows a similar general agreement with the adjusted seed yields of exposed plants, although reasons for the differences in cross pollination values at the two sites are not apparent from the data. Agreement between low efficiency of seed setting with self pollination and a low production of seed is shown for enclosed plants at two sites.

SEED YIELDS AND SIZE OF PLANTS

Despite stimulus of efficient pollination, high production of seed in alfalfa is dependent also upon an adequate size of the plants. The ac-

TABLE 3.—*Effects of excluding pollinating insects and lygus infestation on seed setting with open and cross pollination and showing the relationship of size of plants to seed yields for three sites, season of 1944.*

Site	Flowers forming pods		Yield per plant, grams			Calculated (app.) yield per acre of seed, lbs.	
	Open	Cross	Total plants	Forage (dry wt.)	Seed (recleaned)	Actual	Adjusted*
	1	2	3	4	5	6	7
Dry land region:							
Isolated hill plots:							
Open field	39.4	60.9	66	23.2	3.60	154	315
Under cage	8.9 (self)	66.7	69	24.3	0.24	10	
Sub-irrigated area:							
Open field	33.9	48.8	65	44.8	5.73	245	228
Under cage	10.1 (self)	58.8	69	42.2	0.41	17	
Irrigated region:							
Lygus infestation:							
Dusted	31.2	76.3	70	55.2	4.09	175	130
Not dusted	24.2	72.7	62	62.1	1.54	66	

*Adjustment is limited to the actual mean yields for which statistically significant correlation is obtained between seed yields and size of the individual plants (n = app. 60), as shown in Table 4. The adjustment is one made as a result of the regular analysis involving the use of the regression equation $Y_1 = \bar{y}_1 - b_{yx}(\bar{x}_1 - \bar{x})$, according to Goulden, C. H. Methods of Statistical Analysis. (Page 252.)

tual seed yields of the six clones, as given in column 6 (Table 3), show close relationship to the average dry weights of the plants, as given in column 4. Correlation coefficients based on covariance analysis of the seed yields and dry weights of the individual plants, as given in Table 4, for the various sites, tend to confirm this apparent close relationship. While statistical significance is indicated in some cases, exceptions are noted. The limited number of degrees of freedom available for comparisons seem not to justify definite conclusions as to the significance of differences between the clones. Coefficients calculated within clones, however, afford a better and more accurate estimate of the apparent relationship between size of plants and seed yields. Not only are these (r) values more accurately estimated owing to having available more degrees of freedom, but they are freed from variable effects owing to different genotypes. In other words, high correlation between size and seed yields for the means of clones could be the result of some other factor peculiar to a particular genotype and associated with vegetative development, whereas that possibility does not exist for the correlation between plants within the same clone.

Relationships between seed yields and the size of alfalfa plants show differences owing to factors affecting pollination and seed setting. For example, the exclusion of pollinating insects by means of cages is shown from data given in columns 4 and 5 (Table 3) to have reduced greatly the production of seed, but not to have affected significantly

TABLE 4.—*Correlation coefficients determined from covariance analysis of data on seed yields and size in plants of seven clonal lines, including the red-rooted tester.*

Source of variation	DF	Correlation coefficient (r)
Between the Means of Genotypes		
Dry land regions:		
Isolated hill plots	5	0.92**
Sub-irrigated areas	5	0.51 (not significant)
Irrigation regions:		
Lygus infestation:		
Dusted	5	0.91**
Not dusted	5	0.77*
Within Genotypes		
Dry land region:		
Isolated hill plots	58	0.90**
Sub-irrigated area	57	0.62**
Irrigation region:		
Lygus infestation:		
Dusted	54	0.51**
Not dusted	63	0.23 (not significant)

*Statistically significant at 5.0%.
**Statistically significant at 1.0%.

the size of the plants. Lygus infestation in the irrigated region also reduced significantly the production of seed, but seems to have had no significant effect on the average size of the plants in relation to those for which a partial control of the infestation was affected by frequent dusting. In the open field at the isolated hill plots and the sub-irrigated dry land region where insect pollination was highly efficient and lygus population was low, significant correlation is obtained between the average size of the plants and the actual seed yields, as given in Table 4. While direct relationship between seed yields and size in alfalfa plants seems to hold for conditions favoring seed setting, exceptions may be noted, owing largely to factors inhibiting pollination and seed setting. The importance of large size in plants is nevertheless suggestive of the value of good soils, timely irrigation, and appropriate cultural practices in relation to the production of alfalfa seed.

LYGUS INFESTATION AND SEED PRODUCTION

Treatment in the irrigated region was determined largely from the necessity of having to effect a partial control of lygus infestation for a satisfactory production of seed. Application of a pyrethrum dust was made twice weekly to the plants of one plot, while those of the other were untreated and left exposed to the natural infestation of the region. Data given in column 1 (Table 3) show that 24.2% of the sample flowers formed pods with lygus infestation, as compared with 31.2% for the dusted plants. The greater efficiency of pollination with the possibly lower lygus population is reflected in the higher actual seed yield (175 pounds per acre) by the dusted plants. Uncontrolled infes-

tation is shown to have reduced the production of seed for practical purposes (66 pounds per acre) about as effectively as did the exclusion of pollinating insects (10 to 17 pounds per acre) at the dry land sites. This loss in seed production appears significant when consideration is given to the fact that lygus infestation is a factor affecting large portions of formerly productive alfalfa seed-growing regions, while complete absence of pollinating insects is seldom, if ever, encountered in the practical growing of alfalfa seed.

Direct damage to alfalfa flowers and buds resulting from lygus infestation, as shown by Carlson (4), although important as a factor affecting seed production, has seemed inadequate as the only cause of the major decline in yields in Utah and other western states during recent years. Other effects of infestation have been noted which appear to be important. Data obtained from a study of tripping in flowers of plots receiving different insecticidal treatments are cited as evidence of poor pollination with lygus infestation. Preliminary tests of DDT and sabadilla dusts were made at the Utah Agricultural Experiment Station in 1944.[4] Applications were made in two frequencies, two dosages and in four replications, and lygus populations were determined in relation to treatments given to a total of 64 plots. It soon became apparent that flowering and seed setting were better for the DDT- and sabadilla-treated plots than for those treated with pyrethrum-sulfur dust. The percentage of tripping was then determined for a six-day period of maximum flowering and seed setting, during which a total of 27, 621 flowers were examined. A statistically significant negative correlation (r −0.99) is shown between the percentage of flowers tripping and lygus populations, for the means of four insecticidal treatments (df 2). Tripping was consistently low for all plots treated with the pyrethrum-sulfur dust and about 50% higher for those dusted with 10% DDT. A statistically significant positive correlation (r 0.50) (df 63) is shown between the percentage of tripping and seed yields, which is evidence of the high importance of tripping insect activity in the production of alfalfa seed. The consistently lower percentage of tripped flowers in the lygus-infested plots suggests a possible reluctance on the part of the pollinating insects to visit the flowers of lygus-infested alfalfa. The lack of harmony seems to be attributable not so much to direct competition between the insect species as to an aversion on the part of the bees to frequent the flowers of plants affected by the infestation.

DISCUSSION

Literature cited shows that differences of opinion have long been prevalent regarding the relative importance of factors affecting seed setting and seed production in alfalfa. Present information appears to indicate the predominant importance of four factors, namely, (a) insect pollination and tripping; (b) lygus infestation; (c) varieties and strains of alfalfa and the genotypes of the individual plants; and (d) soils, soil moisture, cultural practices, and other environmental con-

[4]See companion paper of the series by Sorenson and Carlson (pages 495 to 501) in this issue of the Journal.

ditions as affecting growth and development of the plants. Knowledge of other factors, although possibly of less direct significance in relation to the production of seed, has contributed to an understanding of the basic principles of seed setting. The importance of a balanced food supply and food utilization by the embryo, the endosperm, and the integuments has been emphasized by Brink and Cooper (2). A description of ovule development was first made by Reeves (14) and later embryo development received attention from Cooper (6) and Farley and Hutchinson (8), and possibly others, which information has been of value toward a better understanding of the technical problems related to the production of alfalfa seed.

The value of honeybees and wild bees in the production of alfalfa seed is apparent from the work of Dwyer and Allman (7), Hadfield and Calder (10), Tysdal (17), and Knowles (12), the most recent contribution being that of Vansell and Todd, published as a companion paper of the present series. Results of controlled pollination studies appear to leave no question as to the value of pollinating insects in the production of alfalfa seed. Evidence of a decline in their numbers in alfalfa fields because of current agricultural practices, while consistent and conclusive as a cause of poor seed setting and low yields in some areas, appears not to account for the seed crop failures in all regions; instead, the effects of lygus infestation in particular seems in many instances to constitute an unfavorable and often limiting factor under western conditions. Results of recent experiments with DDT and other insecticides show significant improvement in both pollination and seed production with effective control of lygus infestation.

Statistically significant negative correlation between lygus populations of plots receiving different insecticidal treatment and the percentage of flowers tripping brings to light a phase of the alfalfa seed production problem which heretofore had not been recognized. Since tripping is a reliable index of pollinating insect activity in alfalfa fields, low tripping frequency associated with high lygus populations seems to suggest a harmful influence of lygus infestation on the activity of pollinating insects. This relationship might explain the occurrence of poor seed setting in lygus-infested areas, despite adequate flowering by the plants and conditions otherwise favorable to the production of seed.

The close relationship between size of alfalfa plants and the production of seed is significant in relation to factors affecting pollination. In other words, large plants produce the most seed only when pollination is highly efficient and adequate.

SUMMARY

Interest in the problems of alfalfa seed production has been revived largely as a result of greatly declining yields in formerly highly productive areas. Present information appears to indicate the predominant importance of four factors, namely, (a) insect pollination and tripping, (b) lygus infestation, (c) varieties and strains of alfalfa and the genotypes of individual plants, and (d) environmental conditions and cultural practices affecting growth and development of plants.

Three sites were selected for the investigation as being typical of

conditions under which alfalfa seed is produced in Utah and other western states, while clonal lines from six genotypes of known fertility level gave material representative of a wide range in alfalfa types. When insect pollinators were excluded by caging, plants of the various clonal lines produced from 10 to 17 pounds of seed to the acre with self pollination, as compared with 154 and 245 pounds per acre, respectively, with open pollination in comparable adjacent plots at two widely different sites. Similarly, where lygus bugs were a factor, the yield was 66 pounds per acre compared to 175 pounds for nearby plots that were dusted frequently with a partially effective insecticide. Where conditions were favorable for pollination and seed setting, the larger plants produced more seed than did small plants of the same clone, owing in part to the greater abundance of flowers. The relationship between seed yield and size of alfalfa plants, however, is subject to the effects of factors influencing pollination and seed setting.

Data show a statistically significant negative correlation between lygus populations of plots receiving different insecticidal treatment and the percentage of tripping. Since tripping affords a highly reliable index of pollinating insect activity under field conditions, low tripping frequency associated with high lygus population suggests the possibility of an unfavorable effect of lygus infestation on the activity of pollinating insects in alfalfa fields.

The potential seed setting capacity of individual plants and genotypes of alfalfa seems to be closely associated with response to controlled pollination. The effects of cross pollination in particular appear to afford a good index for a preliminary estimation of seed setting potentials, although self pollination stimulated by artificial tripping seems also to have high predictive value for the reason that tripping is an essential condition for highly efficient pollination. The significance of plant genotype in relation to the production of alfalfa seed is apparent from the yields of clonal progenies ranging from 37 to 441 pounds to the acre.

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INFLUENCE OF TRIPPING, SOIL MOISTURE, PLANT SPACING, AND LODGING ON ALFALFA SEED PRODUCTION[1]

H. M. TYSDAL[2]

A LARGE number of individual alfalfa flowers were observed during the period 1938–40 to determine whether flowers had to be tripped to set seed. Observations were made on the causes of tripping, including the effects of insects, rain, wind, environment, and type of plant. In addition, a factorial experiment was conducted on alfalfa seed production in which the plants were spaced 8, 16, 32, and 64 inches apart, grown under different frequencies of irrigation, and in which half of the plants were lodged and half were allowed to make upright growth. This paper reports the results of these studies.

TRIPPING STUDIES

Tripping is the release of the sexual column from the keel of the flower. The sexual column includes the style, stigma, and part of the ovary surrounded by the ten anthers and diadelphous filaments. The sexual column is held within the two keel petals under pressure by interlocking floral parts and when the petals are parted the sexual column snaps forward or "trips" until it comes to rest on the standard petal of the flower. This occurrence is called "tripping".

All evidence indicates that an alfalfa, *Medicago sativa*, flower must be tripped to obtain cross-pollination. It has been suggested that thrips may cause cross-pollination of untripped flowers because they can be observed entering and leaving the keel of untripped flowers, and when observed under the microscope pollen grains usually can be observed adhering to their bodies. However, in an actual test, a large number of thrips were confined within a bag containing flowers of two different plants, the crosses of which could be identified, and no crossing resulted. Some insects seem to be able to collect small amounts of pollen through the opening at the base of the keel without tripping the flower. Although some foreign pollen might be deposited in the keel through this process there appears to be no effective means of producing cross-pollination in the untripped flower.

While it is important to know whether tripping is necessary for

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cross-pollination, it is also important to know whether an appreciable amount of either crossed or selfed seed sets without tripping, and if tripping is necessary, what causes it. This is indeed such a fundamental question that its correct solution is essential to intelligent recommendations for successful seed production.

All workers have not agreed on the necessity of tripping for seed setting in alfalfa. Carlson (4,5),[3] Piper, *et al.* (13), and Brink and Cooper (2) have indicated a considerable proportion of seed setting without tripping. The latter reported that, on the average, 12% of the flowers were tripped and 33.6% of the flowers set pods, and concluded that many flowers were setting pods without tripping. In making these counts a branch was "removed from the plant and a complete census made of all the flowers, pods, and empty floral bracts." In other words, the percentage of tripped flowers at a given time was compared with the number of pods which must have accumulated over a period of time. Following this procedure it would be difficult to determine whether the flowers setting seed were the result of tripping or not. The percentage of freshly tripped flowers in the field at any one time cannot be used as a criterion of whether pods which developed several days before were formed from tripped or untripped flowers. Moreover, it is very unusual to find a large percentage of "open-tripped" flowers present at any one time because the standard petal soon wraps around the sexual column and the flower takes on a wilted appearance. Numerous observations have indicated this process may only take from 30 minutes to 2 or 3 hours, depending upon the temperature and other factors. This "tripped-wrapped" condition is very confusing as it cannot be determined whether it is a wilted flower or a tripped flower without unrolling the standard petal with a suitable instrument, such as a forceps, to see whether the sexual column has actually been released from the keel. As a matter of fact, a raceme showing 12% tripping at any one time indicates a high percentage of tripping because of the above reason and because flowers are receptive over at least 4 or 5 days and 12% tripping per day would mean over 50% of the flowers tripped when they were still in a receptive condition. Fifty per cent tripping could readily account for 33.6% of the flowers forming pods. This point is taken up in considerable detail because it is believed to be of fundamental importance.

In contrast to the reports of setting seed without tripping, Burkill (3), Hackbarth (9), Ufer (16), Armstrong and White (1), Tysdal (14), and Knowles (11) indicate that tripping is necessary for seed production. It is recognized by some of these workers that an occasional flower, or plant, will set seed without tripping, but this does not happen often enough to contribute materially to a commercial crop. Even among these investigators, however, there is no unanimity regarding the cause of tripping. Armstrong and White (1) frequently refer to high seed-setting plants which "automatically trip" or "self-trip" and explain this tripping by the morphology of the tripping mechanism and sensitivity to environmental conditions. Knowles (11) and Tys-

[3]Figures in parenthesis refer to "Literature Cited", p. 534.

dal (14), on the other hand, conclude that tripping depends largely on the activity of beneficial insects.

Data on tripping have been obtained over several years in western Nebraska where alfalfa breeding investigations were conducted utilizing the facilities of the Scotts Bluff Field Station, cooperatively operated by the Nebraska Agricultural Experiment Station and the U. S. Dept. of Agriculture Division of Western Irrigation.

In this nursery there was a relatively high percentage of tripping and a very good seed set. The high percentage of tripping was not difficult to observe when working closely with the plants, but such observations failed to determine the *cause* of the tripping. It was decided, therefore, to observe continuously a number of flowers from the fresh bloom stage to wilting to determine exactly what was happening. The first observations were made in August, 1938, when 12 racemes containing about 10 full flowers each were tagged within a short radius of the observer and watched continuously during daylight hours for 4 days. In this period the weather was warm and sunny. Approximately 70% of the flowers were tripped during this period and not a single one of them was tripped except by the action of insects. None of the untripped flowers produced seed, while a high percentage of the tripped flowers set seed. These results were considered very significant.

Acccordingly, the following year more extensive data were obtained. These bore out the observations made in 1938 and have been reported (13). Additional data, given in Table 1, were obtained in 1939 and 1940. The results were obtained by tagging selected racemes of a number of plants and subjecting them to the following treatment: One set of racemes was tagged, but left to develop normally; observations were made three times a day to determine the amount of tripping and the number of pods developed. On a second set of racemes the flowers were artificially cross-pollinated by gathering foreign pollen on a toothpick and tripping the stigma directly on this mass of pollen. The foreign pollen was not applied after tripping because observations had indicated an apparent lack of cross-pollination by dusting foreign pollen over the tripped flowers. Moreover, the method of cross-pollination used corresponds closely to insect tripping where, usually, the stigma strikes into a foreign pollen mass on the body of the insect. On a third set of racemes all of the tripped flowers were removed, so that any pods formed would be from the untripped flowers. In a fourth set of racemes the full, untripped flowers were covered with fine-mesh muslin bags. In all cases the four complete sets were put on each plant. In 1939, the four sets were placed on each of the 10 plants for each date. In 1940, the same procedure was followed, but 20 plants were used for each date. The same plants were used throughout the season. There were approximately 10 full flowers per raceme, making a total of about 100 flowers per treatment for each date in 1939, except August 21 when only two plants were used, and 200 flowers per treatment for each date in 1940.

To determine whether or not manipulation interfered with seed set, observations were made on racemes from which some of the flowers were forcibly removed as compared to undisturbed racemes except for

TABLE 1.—*Average percentage of flowers naturally tripped at intervals in 1939 and 1940 and percentage forming pods under natural conditions compared with three other treatments, Scotts Bluff Nursery.*

Date flowers selected	Percentage flowers tripped under field conditions	Percentage flowers forming pods			
		Under field conditions	Artificially tripped cross-pollinated	Without tripping	Under bags without tripping
1939					
July 17	20	17	—	5	20
July 27	8	6	83	0	5
Aug. 8	6	3	86	0	1
Aug. 21, plant a	33	9	93	0	2
Aug. 21, plant b	58	28	96	0	—
Average	25.0	12.6	89.5	1.0	7.0
1940					
June 12	84	32	—	5	9
June 19	81	31	—	6	7
June 25	70	44	—	14	10
July 8	19	19	62	2	4
July 17	45	33	76	12	10
July 24	29	5	72	1	2
July 29	17	7	74	2	9
Aug. 6	37	22	72	1	4
Aug. 13	41	26	83	5	7
Aug. 20	34	15	77	1	2
Aug. 27	21	10	74	1	3
Sept. 3	13	4	62	2	2
Average	40.9	20.7	72.4	4.3	5.8

tripping. The removal of flowers did not interfere with the inherent seed-setting capacity of the remaining flowers. Similarly, a test was made to determine whether the muslin bag disturbed seed setting. It was found that 3.6% of the flowers inclosed in the bag and not tripped before covering developed pods, 85.7% of the flowers inclosed in the bag but cross-pollinated before covering produced pods, and 78.5% of the flowers cross-pollinated and allowed to develop on the outside produce pods. These data indicate that the bag in itself apparently did not have a harmful effect on pod setting. During the season the bags were put on as carefully as possible, but it was observed that an occasional flower might accidentally be tripped.

In 1939, the sets were not started until July 17; but in 1940, they were started June 12, and repeated at weekly intervals until September 3. The weekly intervals allowed for the practical completion of one set before the next was put on, except that sometimes the untripped flowers would carry over into the second week. They usually remained turgid 5 or 6 days but in cool weather sometimes stayed fresh as much as 10 days.

The primary objective of the experiment was to determine whether

alfalfa flowers set seed without tripping. As can be seen from Table 1, there was never a high percentage of pods formed from untripped flowers at any date during the entire two seasons under observation. The highest was 14% for the set started June 25, 1940. This percentage is based on the number of untripped flowers, not on the total of both tripped and untripped. The average pod formation from untripped or bagged flowers is low in all cases, the highest being 7% under bags in 1939 and the lowest 1% without tripping in 1939. For the first set bagged July 17, 1938, it is believed some of the flowers may have been tripped in the process of putting on the bags resulting in an unusually high seed set. The bags were more carefully handled in succeeding sets.

The extreme variation in percentage of flowers tripped from week to week is well illustrated in the data given in Table 1. The large changes in percentage tripping are usually reflected in changes in the percentage of flowers forming pods under natural conditions. The correlation coefficient between the percentage flowers tripped and those forming pods for 20 dates on which paired data were obtained (the 17 in Table 1 plus 3 others) was found to be 0.84.

One of the most enlightening comparisons in Table 1 is that between the percentage flowers forming pods under natural conditions as compared with the percentages forming pods when artificially tripped and cross pollinated. On July 24 and 29, 1940, for example, the percentage of flowers being tripped and the percentage forming pods under natural conditions is relatively low, but the percentage of cross-pollinated flowers setting pods is about the same as at the other dates. In other words, it is a lack of tripping and not an inherent change in the plant which has caused the decrease in seed production.

The lack of tripping on given dates can be explained to some extent by reference to Fig. 1 where the daily maximum temperature, daily minimum humidity, and rainfall for the period June 11 to Septemper 27, 1940, are given, along with the percentage of flowers forming pods as determined from the weekly sets reported in Table 1 and additional sets put on to determine only the pod setting under natural conditions. The bars showing percentage of flowers forming pods are given for the day the sets were put on, that is when there were full flowers. Actually the flowers may have been tripped and set pods anytime within the next 4 to 6 days depending on conditions. Thus, temperature or humidity on any one day does not reflect the conditions through which the flowers passed during their receptive period. Temperature and humidities were recorded continuously on a hygrothermograph placed in the nursery. The humidity recorder broke on August 27 and could not be repaired before the end of the season. The minimum temperatures or maximum humidities are not given because they did not vary greatly throughout the summer. The minimum daily tenperatures were usually in the high 50's, and the maximum humidities were usually over 90.

It becomes difficult, therefore, to correlate weekly weather conditions with seed production, and it is easy to see why studies correlating seasonal weather with seasonal production have not yet provided

causes tripping. Here again there is considerable difference of opinion among workers as to whether there is an appreciable amount of "automatic" or self-tripping or whether tripping is dependent on outside forces. On close observation of alfalfa plants it is easy to understand such differences of opinion because some plants trip much more easily than others, and a few are actually self-tripping. It is also evident that weather influences tripping, during bright warm weather flowers will trip much more readily than flowers on the same plant during cool damp weather. One way to determine the ease of tripping is to use alcohol solutions in varying strengths, placing a drop in the "throat" of the flower and determining which strength is sufficient to cause the flower to trip. If, for example, 10 solutions are used varying from about 40 to 85% ethyl alcohol, the plants can be graded on the basis of 1 to 10. If a weaker solution does not trip the flower another flower on the same plant is treated with the next stronger solution. This system has been used on individual plants in the breeding nursery and there appears to be a good correlation between this method and the physical force required to trip the flowers. Unquestionably, a certain percentage of flowers are tripped through the action of rain, wind, and sun, but the importance of such tripping in relation to commercial seed production may well be questioned.

RAIN MAY CAUSE TRIPPING

At the Scotts Bluff breeding nursery the effect of five different showers was observed by tagging full-flowered racemes at various positions on the plants immediately before the showers and observing them during or immediately after showers. The position of the flowers was also noted. The average percentage of flowers tripped in different positions and by brisk and gentle rain is given in Table 2.

TABLE 2.—*The amount of tripping of alfalfa flowers caused by rain, average results of five rains at Scotts Bluff Nursery, 1940.*

Position of flowers on plant	Percentage tripping
Top of plant, fully exposed	10.5*
Side of plant, subject to beating on ground	9.9
Inner part of plant, protected by plant	4.4
Average	8.3
Effect of Rain Intensity	
Brisk rain	11.8
Gentle rain	4.7
Average	8.3

*Approximately 175 flowers in each group.

The fully exposed flowers at the top of the plant showed more than twice as much tripping as those protected by the plant. The average tripping caused by the five rains, considering all positions, was 8.3%.

All of the rains were of short duration, some lasting only a few minutes. The short, sudden downpours were much more effective in tripping than the gentler rains, and they were more effective during warm weather when the sun shone immediately after the rain. As much as 7% tripping has been observed to occur immediately after a shower if warm, sunny conditions prevail. Steady or intermittent rains with relatively cool weather trips very few, if any, flowers. At Lincoln, Nebr., as a result of a half-hour July downpour, 37 flowers were tripped out of 134 full flowers under observation, a total of 27.6%. Spraying water on full flowers on a bright hot afternoon resulted in as high as 37% of the flowers being tripped.

Immediately after one downpour at the Scotts Bluff Station, 135 freshly tripped flowers were marked and followed through to see if they set pods. Of this total eight flowers, or 5.9%, set pods. Since about 80% of the artificially cross-pollinated flowers were setting pods at this time, the rain-tripped flowers set about 7% as many pods as the comparable cross-pollinated flowers. The number of seeds per pod was not determined in this group, but since there seems very little opportunity for crossing with rain-tripped flowers, there is every reason to believe that there would be from two to six times as many seeds per pod in the cross-pollinated as in the rain-tripped flowers, depending on the self-fertility of the individual plants (7, 13). This would accentuate the difference in seed production.

In a further test to determine the effect of water on tripped flowers, a controlled experiment was conducted at Lincoln, Nebr., the results of which are given in Table 3. In this experiment a group of six plants which had a good amount of bloom were chosen in the nursery and several racemes of each were marked, all treatments being applied to every plant. The plants were growing under similar conditions. In one treatment the flowers were first sprinkled, then tripped; in another the flowers were first tripped, then sprinkled; in a third treatment the flowers were sprinkled, then tripped, then sprinkled again; in a fourth, the flowers were tripped; and in the fifth treatment the flowers were tripped and cross-pollinated. All the flowers given the sprinkling treatment were tripped by hand without the addition of foreign pollen, i. e., self-pollinated because it is considered that during a rain there would be very little opportunity for the flowers to be cross-pollinated. The sprinkling was performed with an ordinary sprinkling

TABLE 3.—*Percentage of flowers forming pods when sprinkled with water before and after tripping compared to selfed and crossed flowers without sprinkling.*

Treatment	Percentage flowers setting pods*	Ratio to self pollinated as 100
Flowers sprinkled then tripped	42	75
Flowers tripped, then sprinkled	26	46
Flowers sprinkled, then tripped, then sprinkled	12	21
Flowers tripped, self-pollinated	56	100
Flowers tripped, cross-pollinated	86	154

*Six different plants used, and approximately 100 flowers for each treatment.

can and lasted only a few minutes for each treatment. The sprinkling treatment caused a decrease in the percentage of flowers which set pods. Considering the pods from the self-pollinated tripped flowers as 100%, the flowers which were sprinkled before tripping set 75% as many pods, the ones which were sprinkled immediately after tripping set 46% as many pods, and the flowers which were sprinkled both before and after tripping set a total of 21% as many pods as the self-pollinated flowers not subject to sprinkling. In comparison the cross-pollinated, unsprinkled flowers set 54% more pods than the self-pollinated flowers. Thus, the flowers sprinkled, then tripped, then sprinkled, as would be the case when tripped during a shower, set only 14% as many pods as the cross-pollinated group. This response is comparable to the 7% actually found under field conditions in western Nebraska.

WIND CAUSES VERY LITTLE TRIPPING

Numerous observations have been made during strong wind storms for tripping due to the wind without finding appreciable tripping. During a strong wind full flowers which are beating against the ground or other stationery objects occasionally are tripped, but those in a general field show very little tripping through the action of wind.

SELF-TRIPPING OR SEED SET WITHOUT TRIPPING

There is no doubt that some alfalfa plants trip automatically, i. e., self-trip without the aid of any external force. The percentage of such plants in a commercial strain is very low. Judging from their occurrence in breeding nurseries, the number of plants that self-trip in an unselected population is a fraction of 1%. Actually, only one plant in several thousand under observation in the Nebraska nurseries was found to be self-tripping—and that one was a very poor seed setter! It is also true that an occasional alfalfa plant can be found which sets seed fairly regularly without tripping. One of this type was also found out of several thousand under observation in the breeding program. An occasional flower on a much higher percentage of plants may set seed without tripping, but as has been seen the total number of flowers setting seed without tripping is invariably very low, averaging under 5%, as shown in Table 1.

It is believed that plants which either self-trip or set seed without tripping can be selected and that, probably, a strain can be developed which would have either of these characteristics. The more important question, however, is whether such a strain would be desirable. Judging from all the available results to date, the answer is that such a strain would be low in forage production, because of the selfing involved, and, therefore, such a strain would be of little commercial use.

However, it appears feasible to select relatively self-sterile, easy-tripping plants so that nectar-collecting honey bees would be much more effective, or to select plants more attractive to pollen-collecting honey bees. Plants which are tripped much more readily than others by honey bees have been observed in the breeding nursery. It would seem desirable to consider this possibility in alfalfa-breeding programs.

MACHINE TRIPPING

A good many tests have been made by various investigators and growers in this Country and in Canada (10) on the use of some sort of machine or drag for tripping to stimulate seed production. Although a few machines have caused some flowers to trip, none has been shown to increase seed production materially. If a machine can be built which will trip and cross-pollinate the flowers and which can be put over the field several times, during the flowering season, economically and without injuring the plants, then machine tripping might be successful. It would seem difficult, however, to construct such a machine.

CONCLUSIONS REGARDING TRIPPING

It has been shown that whereas rain, sun, and wind may cause some tripping in alfalfa, such agents are very ineffective for the production of substantial seed crops. Moreover, self-tripping or setting seed without tripping is not of frequent occurrence, and probably is undesirable when it does occur. In fact any or all of these agents would be harmful to optimum seed production when compared to the amount of seed which could be obtained from the same flowers by cross pollination.

The fact must be faced therefore that cross-pollinating insects are required for successful alfalfa seed production. In the vast majority of cases (at least 99 out of 100 fields), there are insufficient beneficial insects to do the job. Of the hundreds of fields observed by the author for seed production only one has had an optimum population of beneficial insects. In this case the flowers were being tripped as they were coming out of the bud stage. No full flowers were to be found and the field had a grayish appearance instead of showing profuse bloom. This field was going from the "bud to the curl", as old timers used to describe exceptionally good seed fields. One of the big problems in alfalfa seed production is to determine how best to provide a population of these beneficial insects either by propagation of the efficient wild insects, by providing them proper places to live near alfalfa fields, and by other means, or by making the use of honey bees more effective by selection of the proper type of plants or bees. Providing for an abundance of these beneficial insects, together with the elimination of plants competing for beneficial insect visitation during the time alfalfa is in bloom, is an important "must" for consistent, successful alfalfa seed production.

EFFECTS OF SOIL MOISTURE, PLANT SPACING AND LODGING ON SEED PRODUCTION

SOIL MOISTURE STUDIES IN THE GREENHOUSE

In controlled experiments conducted by Clark (6) at the Nebraska Agricultural Experiment Station, plants were grown in soil with different moisture contents in the greenhouse in 3-gallon glazed jars. The three degrees of soil moisture were so selected that for one group the soil moisture was below optimum for plant growth, in another group soil moisture was near optimum, and in the third group the

soil moisture was somewhat above optimum. The water content of the soil was 20, 30, and 40% on a dry weight of soil basis for the low, medium, and high soil-moisture groups, respectively. The hygroscopic coefficient of the soil used was about 12. The different degrees were maintained by weighing the pots on alternate days and restoring the water lost by evaporation and transpiration. Evaporation was reduced to a minimum by covering the soil with 2,000 grams of clean, fine gravel.

The low soil-moisture group was started at 17% water content. It was found that at this level the amount of available water was so limited that the plants were apt to become severely wilted on any warm day even when the water loss was restored daily. The water content of the soil, therefore, was increased to 20% early in the season and held at that throughout the remainder of the season. At this level the plants kept thrifty, but made a somewhat stunted growth.

Table 4 gives the green weight, number of stems, number of racemes, number of flowers per raceme, number of pods per raceme, weight of 100 seeds, weight of seed per 100 grams green weight, and yield of seed per plant resulting from the controlled moisture experiment. There were 10 plants each of four different strains tested, but since all strains responded similarly only the averages are given in the table. All of the flowers on all of the plants were tripped by hand when they were in full bloom, without the addition of foreign pollen. The high moisture group produced more seed than either the low or medium moisture groups. On the average, the low moisture group of plants produced considerably less seed than either the medium or high moisture groups.

The green weight per plant averaged highest in the high moisture group and varied between the different classes in the same direction as the seed production. The seed production of the high moisture group, however, produced slightly more seed per 100 grams of green weight than either the medium or low moisture groups as shown by the next to the last entry in Table 4.

Thus, both actually and relatively, the plants growing in the higher moisture levels produced more seed than the low moisture group, indicating that moisture in itself has not reduced the inherent seed-setting ability of the plants, but rather increased it. These results are in agreement with those obtained by Grandfield (8).

SOIL MOISTURE AND LODGING STUDIES IN THE FIELD

In order to determine the amount of seed production of alfalfa plants growing with different soil moistures under field conditions with different spacings and with plants lodged compared to upright growth, a planting was made at the Scotts Bluff Field Station in 1938. Plants of two strains were transplanted to adjacent blocks with 8-inch spacings (each way) between the plants in one block, 16-inch spacings in another, and 32-inch spacings in a third block. There were 144 plants of each variety in the 8-inch spacings, 48 in the 16-inch spacing, and 24 in the 32-inch spacing in each block. During the summer different irrigation treatments were given to the two main blocks,

TABLE 4.—*Vegetative, flower, and seed production of four strains of alfalfa grown at three different levels of soil moisture in glazed jars in the greenhouse.*

Character and unit of measurement	Soil moisture content		
	Low	Medium	High
Green weight, grams per plant	107	131	148
Number of stems per plant	55	57	67
Number of racemes per plant	390	583	548
Number of flowers per raceme	10.1	9.8	10.5
Number of flowers per plant	3,939	5,713	5,754
Number of pods per raceme	0.63	0.70	0.75
Weight of 100 seeds, grams	0.187	0.196	0.203
Grams of seed per 100 grams green weight	0.86	1.25	1.51
Seed per plant, grams	0.92	1.64	2.23

each containing the three different spacings. One was irrigated nine times, and will be called the high moisture block, whereas, the other was irrigated only twice and will be called the low moisture. The two varieties were not interplanted so when different irrigation treatments were applied it was necessary to apply the frequent irrigations to one variety only, while the other had the low moisture conditions. It is believed the data obtained are comparable, however, because in the second year the treatments were reversed with much the same results as in the first year, and because the response of the varieties was rather similar throughout. Not only were the treatments on the high and low moisture blocks reversed in 1939 as compared with 1938, but the plant treatments were also reversed, that is, the lodged plants in 1938 were the upright plants in 1939 and *vice versa*.

The irrigation treatments were determined by the growth of the plants. In the high moisture block the plants were kept in a succulent, vigorously growing condition throughout the summer, but the soil, which was a fairly fertile sandy loam type, was never water-logged. The low moisture block was irrigated only when the plants began to wilt slightly from lack of moisture. This block, however, cannot be considered as "droughty" because the plants made a relatively good growth.

In addition to the irrigation differences part of the plants were subjected to a lodging treatment. Many commercial fields had been observed where the fields were so heavily irrigated or where growth was so rank that lodging occurred. In this test instead of waiting for the plant to lodge they were "lodged" by hand by carefully bending the stems over and keeping them horizontal by wire staples which were driven into the soil. The stems were not held tightly to the ground, they were not broken, and they continued growing, but in all cases the crown of the plant was left free of upright stems. The plants in alternate rows in each of the high moisture and low moisture blocks were lodged when they started to bloom. After lodging, the plants immediately started new growth from the crown. When this new growth started blooming it also was lodged. Following this procedure it was found necessary to lodge the plants three times during the

summer of 1938 and twice during the summer of 1939. In the thickly planted material the lodged stems were shaded to a considerable extent by the new growth and the upright growth of the adjacent rows.

The combined data, including the forage, flower, and seed production per plant and per acre for the two years, 1938 and 1939, are given in Table 5. In forage production (green weight), the plants grown with high soil moisture were consistently higher than the plants grown with low soil moisture as would be expected. The upright plants produced a greater yield than the lodged plants under both the high and low moisture conditions. In this case, therefore, the lodging tended to reduce the total growth although many more new shoots were started on the lodged plants.

Of greater interest is the effect on seed production. The upright plants produced from two to five times as much seed as the lodged plants. The differences in flower production were not as marked as in seed production, and the reduction in seed production was greatest with the thicker planting and heavier watering under the lodged condition. In all cases lodging materially decreased seed production over the comparable nonlodged treatment.

TABLE 5.—*Forage, flower, and seed production of alfalfa plants planted in the spring of 1938 and grown at different spacings, different levels of soil moisture, and under upright and lodged conditions at Scotts Bluff, Nebr., averages for the two seasons, 1938 and 1939.*

	Treatment of plants*	Spacing of plants					
		High soil moisture†			Low soil moisture†		
		8 in.	16 in.	32 in.	8 in.	16 in.	32 in.
Forage, grams per plant	Upright	84	251	653	45	146	477
	Lodged	50	161	462	36	113	382
Forage, lbs. per acre	Upright	18,150	13,532	8,819	9,723	7,887	6,435
	Lodged	10,696	8,679	6,239	7,779	6,077	5,152
Flowers, number per plant	Upright	962	36,009	87,037	5,833	14,398	59,166
	Lodged	827	8,170	49,619	5,774	10,484	41,458
Flowers, number per acre‡	Upright	94,285	882,345	533,177	571,688	352,801	362,443
	Lodged	81,054	200,193	303,960	565,906	256,895	253,966
Seed, grams per plant	Upright	0.12	0.75	4.32	0.29	0.80	4.99
	Lodged	0.03	0.15	1.64	0.13	0.30	1.90
Seed, lbs. per acre	Upright	26	41	58	63	43	67
	Lodged	6	8	22	28	16	26

*The upright growth was lodged by gently forcing the stems over and holding them near the ground with wire staples. This was done three times in 1938 and twice in 1939 in each case when the upright shoots had about 10% bloom.

†In 1938, the high moisture plots were irrigated nine times, the low moisture plots twice. In 1939, the high moisture plots were irrigated ten times, the low moisture plots twice.

‡Last three digits omitted, e.g., there were 94,285,000 flowers per acre at the 8 inch spacing, under upright and high moisture treatments.

In 1939 a new planting was made to study this problem in greater detail. A $2 \times 2 \times 2 \times 3$ factorial was laid out with four replications. The factorial consisted of two varieties (planted in alternate rows in the same plots) with two irrigation treatments with two types of growth (upright and lodged) and with three plant spacings, 8, 32, and 64 inches, between the plants. The individual plots were approximately 1 rod square.

A good stand was obtained in 1939 and was mulched with straw in the late fall so as to reduce any possible winter injury. The straw was removed early in the spring and all plots were given an irrigation. Subsequently, some of the plots, hereafter called the wet plots, were given five additional irrigations on July 10 and 17, and August 7, 12, and 23. The remaining plots, hereafter called the dry plots, were irrigated July 10 and August 12. All plants on half of the wet plots and the plants on half of the dry plots were lodged June 10 and July 18. The plants of the 32- and 64-inch spacing were lodged a third time on August 26. The lodging of the plants was performed by hand with the stems being carefully bent over and pinned down with wires stuck into the ground. The date of lodging was determined by the stage of growth, the plants being lodged when the new growth was in about one-tenth bloom. Yields were taken on all plots October 18, 1940. Forage weights were determined as well as seed yields. Before harvest, a count of the number of stems per plant, average number of racemes per stem, and average number of flowers per raceme was made so as to permit the calculation of the number of flowers per plant, as well as to get an idea of the effect of the treatment on the type of plant. The number of racemes produced during the entire season was counted so the number of flowers represents the total number during the season. The results are given in Table 6.

The two strains, A-110 and A-111, which were planted in alternate rows in the plots differed very little with respect to both forage and seed production. Their average yields are therefore combined in Table 6.

As in the previous tests, the highest forage production per acre was in the upright, close spacing, with frequent irrigation. The lodged plots of the same spacing and irrigation, however, were not as low in yield comparatively, as in the previous test, the 8-inch lodged yielding 7,130 pounds per acre, green weight; while the 8-inch upright yielded 7,562 pounds per acre. The 32-inch spaced plants yielded somewhat less than the plants spaced 64 inches apart on a per acre basis. This difference cannot be explained from the data at hand.

In seed productivity the yields closely follow the trends found in the previous two years. The main exception is with respect to the dry, upright, close-spaced plants. In 1938–39, this treatment was relatively high in seed yield; it was relatively low in 1940. This may be partly accounted for by the fact that in 1940 the dry plots actually got somewhat too dry on one or two occasions, which may have reduced their yield, particularly in the thicker plantings.

The lodged plots, in every case, produced less than the corresponding upright plots. The difference, however, in the 64-inch spacing cannot be considered very significant, especially with the low soil moisture

TABLE 6.—*Forage, stem, flower, and seed production of alfalfa plants planted in 1939 and grown at three different spacings, two levels of soil moisture, and under upright and lodged conditions, Scotts Bluff, Nebr., Field Station, 1940.**

	Treatment of plants†	Spacing of plants					
		High soil moisture‡			Low soil moisture‡		
		8 in.	32 in.	64 in.	8 in.	32 in.	64 in.
Forage, grams per plant	Upright	35	304	1,787	28	257	1,479
	Lodged	33	380	2,028	23	263	1,461
Forage, lbs. per acre	Upright	7,562	4,105	6,033	6,050	3,471	4,993
	Lodged	7,130	5,132	6,847	4,970	3,552	4,933
Stems, number per plant	Upright	26	72	204	23	59	192
	Lodged	59	118	238	35	92	206
Flowers, number per plant	Upright	5,264	30,839	85,415	3,626	20,887	72,664
	Lodged	9,095	36,889	89,851	3,253	20,640	72,424
Seed, grams per plant	Upright	0.28	6.15	25.49	0.16	3.89	23.69
	Lodged	0.03	3.57	16.21	0.06	2.90	22.21
Seed, lbs. per acre	Upright	60	83	86	35	53	80
	Lodged	6	48	55	13	39	75
Shrivelled seed, %	Upright	5.0	4.7	8.2	9.5	3.7	7.2
	Lodged	19.9	4.9	8.6	19.2	3.8	5.6

*Each figure is an average of four replications of each of two varieties, i.e., results from eight plots.

†Plants in the 8-inch spacing were lodged by hand twice during the season (June 10 and July 18) and those in the 32- and 64-inch spacing on the same dates and on August 26. In all cases the plants were lodged when the upright shoots had about 10% bloom.

‡The high moisture plots were irrigated five times during the season, the low moisture plots twice.

level, but the difference becomes greater the thicker the plantings. The 8-inch spacing heavily watered and lodged produced only 6 pounds of seed per acre as an average of both strains, while the corresponding upright plots produced 60 pounds per acre, or 10 times as much. In contrast to this the lodged, heavily watered plants produced more flowers than the upright plants at all three spacings. Thus in adjacent field plots of the same varieties one treatment produced much more bloom, but the other treatment (upright growth) produced much more seed.

Among the more important factors which may have produced this result there are at least three that should be mentioned. First, lack of pollinating insects; second, too many harmful insects; and third, the new growth may have diverted the necessary nutrient supply from the flowering parts or maturing seeds. With reference to the first factor, it is known that there were insufficient beneficial insects throughout the plots to trip and effectively pollinate all the flowers produced. In fact, if there had been enough, the seed production would have been much higher under all treatments. The insects which were present may have

selected the upright growth in preference to the lodged material for their work. Time did not permit a record of the percentage of flowers tripped under each of the conditions. A similar but opposite preference for the lodged plants may have been shown by harmful insects, such as Lygus bugs which are known to prefer succulent growth to more woody, dry growth. While the population of Lygus bugs was not high, there may have been sufficient to modify the results. The third factor, that of diverting the nutrient supply, is difficult to establish, but it is known that alfalfa makes its new growth from the crown at the expense of root reserves when the old tops are removed. The excessive new growth started in the lodged material, shown by the increased number of stems per plant in Table 6, must certainly have required a large amount of nutrient material. The fact that there was over 19% shrivelled seed in the lodged, thickly planted material compared to 5% in the upright material lends support, though not proof, of the lack of a nutrient supply to the developing seed in the lodged material. It is clear that such a complex interaction requires the experimental control of these and perhaps other factors in order to determine the fundamental principles. The differences between seed production in the lodged and nonlodged material, however, are so striking and consistent that it seems safe to conclude that lodging and new growth are detrimental to alfalfa seed production.

Practical seed growers often find that flowers strip badly if the seed field is heavily irrigated just at the time of bloom. Other growers make it a point to irrigate just as seed is being set. These apparently contradictory practices can be explained if in the first case new succulent growth is initiated which may have a deleterious effect on both effective pollination and seed development, whereas in the second case the irrigation is light enough, or conditions are such that very little new growth is started, in which case the additional moisture is probably favorable for filling out the seed.

The three years' results for the 8- and 32-inch width spacing on seed and forage production per acre were averaged and the trends are shown in Fig. 2. This more clearly brings out the harmful effect of too much moisture on the thick planting under both the lodged and upright growth as well as the relatively little influence of high moisture as compared to the low moisture under the wide spacing. These results check with general field observations that under relatively unfavorable conditions (produced as a result of high moisture in this case) the very thin plantings usually average higher in seed production than thick plantings. The trends also indicate an almost reverse effect in forage production, the high moisture, thick planting having the highest forage production and the high moisture, lodged treatment producing next to the highest forage yield but the lowest seed production. The fact that equally good seed production was obtained at the wide spacings with high soil moisture levels indicates that the high soil moisture, as such, is not an inhibiting factor in seed production. However, a high soil moisture content, especially just preceding or during bloom, might result in making the blossoms less attractive to tripping insects, thus lowering seed production.

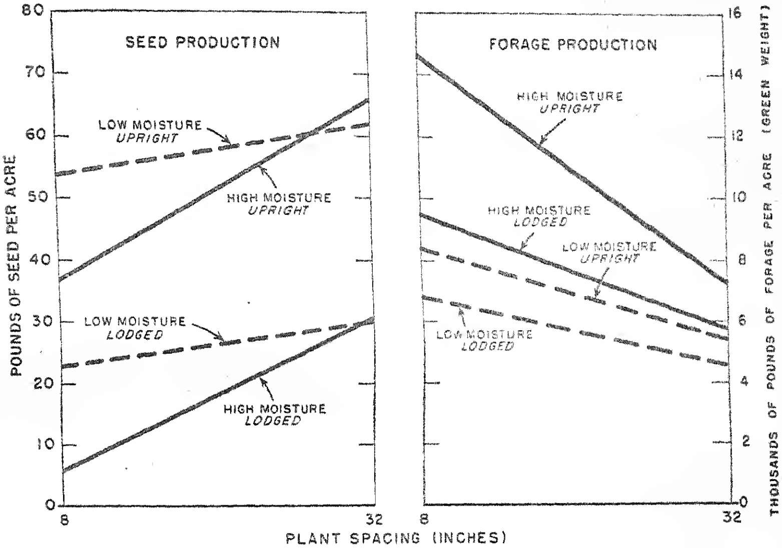

FIG. 2.—Seed and forage production of alfalfa plants grown with different soil moistures, different spacing, and under lodged and upright conditions.

DISCUSSION

Sufficient information has been obtained from numerous experiments to show that further research looking toward consistently successful alfalfa seed production might well be undertaken along four rather specific, yet broad lines of attack. These four lines of attack may be briefly defined as those relating to (a) beneficial insects, (b) harmful insects, (c) plant growth, and (d) plant selection. Much is known regarding each of these categories but in many cases the procedures required to make use of this knowledge are still to be determined. The general status of present information and some of the problems are indicated below.

The necessity for tripping, including cross-pollination, by beneficial insects for successful seed production can no longer be questioned. Lack of an abundance of pollinating insects is probably the most important limiting factor in alfalfa seed production at the present time. Many beneficial insects have been identified during several years of observations, and the following genera of bees have all been observed to trip alfalfa: *Megachile*, *Nomia*, *Bombus*, *Melissoides*, *Calliopsis*, *Apis*, *Halictus*, *Agepostemon*, *Anthidium*, *Augochlora*, *Anthophera*, and *Andrenids*. The soldier beetle, *Chauliognathus basalis*, when feeding has also been observed to trip flowers. No doubt other genera could be added and will be added to this list as further observations are made. No attempt has been made to rate these genera according to their relative importance, but many species of *Megachile*, or leaf cutter bees, are found over most of the country. The *Nomia*, or ground or alkali bee, is found chiefly in the western states. Both of these are very

efficient trippers. Honeybees, *Apis* sp., as is shown by Vansell and Todd (pages 470 to 488) and by Hare and Vansell (pages 462 to 469) in this issue of the JOURNAL, may be quite effective trippers when collecting pollen. The author has observed honey bees vigorously collecting pollen, and thus effectively tripping alfalfa flowers in several seed sections in the United States. This was particularly true in the Antelope Valley of California and in certain areas of Millard County of Utah. Both areas are characterized by a scarcity of pollen sources other than alfalfa. In many areas the difficulty seems to be to get the honey bees to collect pollen from alfalfa when there are many other plants present from which they prefer to collect it. The elimination of pollen plants competing with alfalfa during the seed-setting period appears highly desirable where possible. The propagation of or at least the providing of homes for wild bees or the more effective utilization of honey bees are problems in need of solution.

Harmful insects are undoubtedly of overshadowing importance in alfalfa seed production where they occur in abundance. Lygus is one of the more important harmful insects, but the alfalfa plant bug, *Adelphocorus* sp., Says plant bug, *Chlorochroa sayii*, (Stal.), chalcis fly, *Bruchophagus funebris*, alfalfa weevil, *Hypera postica*, potato leaf-hopper, *Empoasca fabae*, grasshoppers, *Melanoplus* spp., and others must be considered. The advent and use of DDT or other insecticides may be a tremendous boon for alfalfa seed production as shown by Sorenson and Carlson, (pages 495 to 501) and by Lieberman (pages 489 to 494) of this issue of the JOURNAL. Best methods of application of this or other insecticides and their effect on the benficial insects and on the plants and the hazard of poisoning stock fed on the treated crop, however, must be determined.

A study of plant growth in relation to seed production has many ramifications. As shown by the lodging studies, changes in the physiological conditions of the plant which may be associated with recurrent new growth are very harmful to seed production. Soil treatment, such as applications of boron in the eastern United States (12), have increased seed production. Recent work by Grandfield (8) indicates that high food reserves in the plant are beneficial to high seed production. Thickness of planting is also another factor among a whole host of factors related to this problem and inter-related soil fertility problems. In general, relatively thin planting with a normal, steady, almost vigorous growth of the plant without sufficient stimulus to start much new growth from the crown appears to give the best possibilities. In planning the time for the crop to come into bloom average weather conditions and the period of maximum beneficial insect and minimum harmful insect populations should be taken into consideration. This involves studies of the life cycles of the insects. If it becomes possible to control harmful and beneficial insect populations, the whole problem of cultural practices as related to seed production will require re-investigation, because in most of the studies to date the insect factors were not controlled and may have overshadowed any differences due to the treatment of the crop.

Plant selection is not to be discounted simply because it is listed last. Marked differences in seed production of various strains and

selections are given by Carlson (pages 502 to 514) in this issue of the JOURNAL. Some of the self-fertility relationships and their significance in a breeding program and the possibilities of hybrid alfalfa are becoming better known (15). In selection, the self- and cross-fertility relationships should be given careful consideration, and preferably selection should be toward self-sterility. Some of the new hybrids and polycrosses have out yielded the better standard varieties in seed production by more than 40%. It should also be pointed out that plants differ grealy in ease of tripping. Plants have been found in the breeding program whose flowers are tripped rather freely merely by having nectar-collecting honey bees light on them. Possibilities of incorporating such characteristics in superior strains are being investigated. In some cases diseases are responsible for seed failures. Resistance to these might be possible in a breeding program for seed production. There is clear evidence, therefore, that selection and breeding for seed production hold great promise. The genetics, cytology, and embryology of the plant should be given much more study and the significance of the tetraploid condition in alfalfa should be given consideration.

The weather has not been mentioned in this discussion for several reasons, one of which is that it is difficult to do much about it. While the weather is probably the dominating influence in seed production in the eastern half of the United States, it cannot, in many cases, explain the ups and downs in alfalfa seed production in the western states, especially under irrigated conditions. In 1926, Utah produced over 25,000,000 pounds of alfalfa seed. During the last 10 years, the average production in that state has been about 4,000,000 pounds. In all probability, weather has played a minor roll in this change. An increase in harmful insects and a decrease in the abundance of beneficial insects, together with a greater population of plants more attractive than alfalfa to the beneficial insects are probably the determining factors. Under conditions of central and eastern United States, weather has at least a three fold influence. It influences growth, including stimulating new growth at the wrong time for seed production. It influences the abundance and activity of beneficial insects, and it influences the abundance of harmful insects, such as the potato leaf hopper, and others. The effect of the weather on beneficial insects is well illustrated in the data in Table 1, where the percentage of tripping by insects was greatly reduced on July 29, for example, as was also the percentage of flowers forming pods, but the plants themselves when cross-pollinated by hand set just as much seed as in the previous weeks. The weather had affected the activity of the insects, not the plants. In addition, the weather can influence insect populations, both beneficial and harmful, from year to year. Thus, the weather may have a carry-over effect which might be a determining factor in seed production the following year even though weather conditions are then favorable.

SUMMARY

Seed production studies of alfalfa for the three years 1938–40 conducted cooperatively in Nebraska showed that, on the average, less

than 5% of the flowers set seed without tripping (tripping being the release of the sexual column from the keel). Rain, sun, and wind may cause some tripping and there is a limited amount of self-tripping and setting seed without tripping. However, such tripping and seed setting is relatively unimportant for seed production when compared to the amounts of seed produced by cross pollination and ordinarily all of them together will not cause sufficient tripping to produce satisfactory seed crops. Tripping and cross-pollination are caused chiefly by beneficial insects, including wild bees, honey bees, and a few other insects. It is concluded, therefore, that for consistent, successful alfalfa seed production, tripping of the flowers by beneficial insects is necessary and that in practically all fields at the present time there are insufficient beneficial insects.

The effects of different levels of soil moisture were studied in the greenhouse and in the field with different plant spacings and under lodged and upright conditions of growth. In the greenhouse, plants grown in 3-gallon jars with high soil moisture content produced more seed than those grown at medium or low soil moisture. In the field, the plants growing in soil of relatively low soil moisture content produced more seed than those in high moisture at the thick planting rate, i. e., plants spaced 8 inches each way. When the plants were spaced 32 inches, however, the low and high soil moisture plots produced about the same amount of seed, thus indicating that a high soil moisture content, as such, is not an inhibiting factor in seed production. Lodging the plants at the time of bloom by bending the stems and fastening them down greatly reduced seed production as compared to similar plants growing in the normal upright manner. This was true in all comparisons, even though in some cases the lodged plants produced more flowers than the upright plants. The lowest seed production in all comparisons was from the thickly planted, frequently irrigated, lodged plants. The lodged plants produced much more new growth, as shown by many more stems per plant, and they produced 20% shrivelled seed compared to 5% for the upright plants.

In the discussion the present knowledge and future problems of alfalfa seed production are considered under the four headings (a) beneficial insects, (b) harmful insects, (c) plant growth, and (d) plant selection.

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CONTAMINATION OF COTTON FIELDS BY 2,4-D OR HORMONE-TYPE WEED SPRAYS[1]

GLEN STATEN[2]

IN THE spring of 1945, weed sprays commonly known as 2, 4-D or hormone sprays, containing an active ingredient of 2, 4-dichlorophenoxyacetic acid or a modification thereof, were made available to the New Mexico Agricultural Experiment Station for experimental purposes. At the same time certain commercial preparations containing 2, 4-D were available to farmers in limited quantities. There was a great amount of interest in these sprays in the southern irrigated valleys of New Mexico, and all materials which could be secured by growers were being used before experimental results were obtained in the area.

Shortly after the sprays came into use, spots with very abnormal growth were observed in fields of cotton. Affected areas occurred adjacent to locations where weeds had been treated with the hormone-type sprays. Since cotton is a very important crop in this area, it seemed advisable to determine how the contaminating agent was carried to cotton fields and also how sensitive the cotton plant was to the materials.

SYMPTOMS OF CONTAMINATED COTTON PLANTS IN COMMERCIAL FIELDS

On exposure of cotton plants, the formative effect of the chemical is first noted near terminal growing points (Fig. 1). In commercial fields a time lag of 2 to 5 weeks occurred between exposure and first visible symptoms. First effects are rolling and ruffling of leaves at the outer margins. Observed at a distance, these symptoms may be confused with a need of water by the plants. As the injury develops, affected leaves are much modified, narrowed, closely veined, and deeply lobed, resembling somewhat the normal bract surrounding the flower. When the material is absorbed by the developing flower, it is modified similarly to the leaf, becoming elongated and narrowed. Bracts are also modified, being deeply lobed, elongated, and tending to form a sheath around the developing boll.

The degree of effect depends on amount of contamination. In young plants enough material may be absorbed to kill the terminal bud, in which case the plant becomes much branched, the effect resembling that resulting from topping. Branches may develop normally but on a greater degree of exposure also show a formative effect. When branches develop normally, the only injury is delayed maturity, which may cause a decrease in yield. If the exposure is very light, abnormal foliage may develop and gradually disappear, in which case the effect on crop yield is negligible. While the greater portion of affected bolls is lost, some continue to develop and produce open bolls

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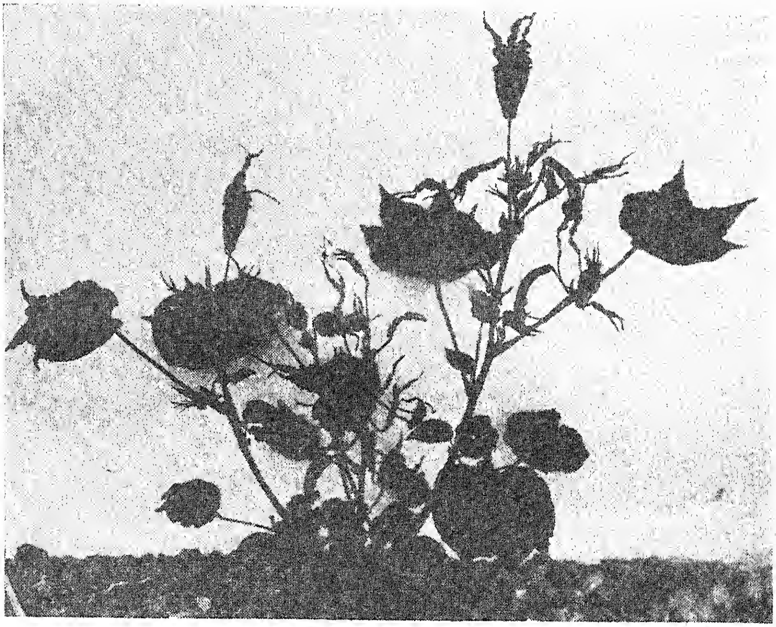

FIG. 1.—The terminal bud of this young cotton plant in a commercial field has been killed by hormone weed spray, causing a much-branched plant. Branches also show hormone effect in abnormal foliage and bracts.

(Fig. 2). No observable difference could be found in length and fineness of fiber produced by affected bolls as compared with normal bolls of the same age.

Affected areas varied in size from about 1/4 to 8 or 10 acres. Degree of injury was usually greater near the source of the material and became progressively less severe as distance from the center of exposure increased. Very few plants in affected areas escaped injury. In one instance effect was observed over a distance of 600 feet to the north of the point where spray had been applied to weeds, and 200 to 300 feet south of the center of exposure.

WATER CARRIAGE

MATERIALS AND METHODS

To determine whether or not intermittent irrigation water carried by ditches can absorb 2, 4-D from ground surface and carry it to cotton fields, a lateral ditch 60 feet long and 5 feet wide was built across one end of a border of cotton containing 1/6 acre. The surface of the ditch was sprinkled with 7.5 gallons of a solution containing 24 grams of ammonium 2, 4-dichlorophenoxyacetate. The material was applied with a sprinkling can to avoid any possibility of its being carried to cotton plants by spray drift. As soon as the surface of the ground was thoroughly dry, cotton was irrigated through the treated ditch, which was used for the remainder of the season.

To determine whether the hormone materials can be leached from dead weed tops by irrigation water and carried to cotton fields, 100 grams of dead bindweed tops which had been killed by a spray containing the sodium salt of 2, 4-dichloro-

FIG. 2.—A plant affected by hormone weed spray after it had set a partial crop of fruit. All except the unaffected bottom bolls on such plants will be lost.

phenoxyacetic acid were tied securely in a 10-pound cloth bag. The bag was then immersed in 55 gallons of water for 2 hours. An area 4 feet 8 inches square, including 13 plants, was bordered in a field of rapidly growing cotton. On June 26 these plants were irrigated with the 55 gallons of water after removing the bindweed tops and thoroughly stirring. The irrigation, approximately 4 acre inches, was comparable to a normal irrigation. On July 13 the border was re-irrigated with 55 gallons of water in which another lot of bindweed tops had been soaked overnight.

RESULTS

At no time during the season was there evidence of injury to cotton plants which were irrigated through the treated ditch. In the second experiment, only one abnormal plant appeared out of the 13 included in the border irrigated by water in which dead bindweed tops had been leached. This plant showed abnormal symptoms on July 14 that were probably the result of contamination by the first irrigation.

In gathering dead bindweed tops it was impossible to secure vegetation free of soil, some of which filtered through the bag into the water. It is felt, therefore, that the one abnormal plant may have been contaminated by soil which had received weed spray direct, rather than by material which had been leached from vegetation by irrigation water.

In view of these results it is believed that when materials similar to those used in the above experiments are applied to irrigation ditches there is no great danger of contaminating cotton fields by irrigating through treated ditches, since irrigation water did not absorb the material from the ground surface or leach it, to any extent, from dead vegetation. The possibility is not excluded that rapidly flowing water in the process of erosion may carry silt and dried vegetation containing hormone materials to cotton fields. Although the experimental results are negative, it should be emphasized that, if only a trace of the hormone is introduced into irrigation water, sensitive crops, such as cotton, can be severely injured. Therefore, indiscriminate spraying of ditches should be avoided and precautions observed to prevent contamination of irrigation water by any means.

OBSERVATIONS ON SPRAY DRIFT

On May 31, 3 square rod plots of bindweed adjacent to a field of cotton were sprayed, the outside boundary of the plots being 2 feet away from the first row of cotton. The solutions used contained 1,000, 2,000, and 3,000 p.p.m. of ammonium 2, 4-dichlorophenoxyacetate and were applied at the rate of 2 gallons per square rod. Spraying was done from 3:45 to 4:45 p. m., during which time a wind velocity of 13 miles per hour was recorded at the official weather observation station approximately ½ mile away. The wind direction was west, occasionally southwest, and directly into the adjacent cotton field. A compressed air knapsack sprayer with Vermorel nozzle was used. The spray nozzle was held approximately 3 feet from the ground during spraying and was accidentally discharged sideways into the air two or three times. Conditions were, therefore, conducive to spray drift directly into the cotton field.

Cotton plants showed injury from spray drift over a distance of 60 feet from the boundary of the plots. Subsequent observations showed that visible bulk of spray drift settled in 30 to 70 feet when equipment mentioned above was used. Later observation indicated that by using a nozzle producing a coarser spray, by spraying when wind direction was away from adjacent cotton, and by careful operation, weeds can be sprayed within 3 to 5 feet of adjacent cotton without injury from spray drift when material is used similar to that in the above experiment.

Since injury was observed in commercial fields over far greater distances than could be explained by spray drift, it was concluded that field contamination came from another source. However, when weeds near cotton are sprayed, care must be exercised in handling equipment, so that no injury will result from direct spray drift.

VOLATILITY OF HORMONE MATERIALS

MATERIALS AND METHODS

The materials used for these tests were commercial brands and formulae supplied by various companies, some of which were available for retail trade, others being supplied for experimental use only. Active ingredients, dilutions, and amounts used are shown in Table 1.

TABLE 1.—*Active ingredients, amounts, and volume of hormone spray materials used in volatility experiments.*

Material No.	Active ingredient	Percentage of active ingredient in stock material	Amount of stock material used	Volume when diluted, cc
1	"Esterified" 2,4-dichlorophenoxyacetic acid	9.6	10 cc	800
2	Ammonium 2,4-dichlorophenoxyacetate	100.0	0.8 gram	800
3	Sodium salt of 2,4-dichlorophenoxyacetic acid	70.0	1.2 gram	800
4	2,4-dichlorophenoxyacetic acid	75.0	1.0 gram	800
5	2,4-dichlorophenoxyacetic acid	9.6	10 cc	800

For test No. 1, the diluted solutions contained in quart milk bottles were placed at 60-foot intervals in the shade in drill rows of cotton on July 19. Bottles were inserted in the soil with about 3 inches of bottle top extending above the soil surface. For test No. 2, material No. 1, diluted as indicated in Table 1, was used. The solution, in a pan 12 inches in diameter and 5 inches deep, was placed in a drill row of cotton on July 24 in a position exposed to the sun. For test No. 3, on August 3, each of the five materials listed above was put in a pan like that used in test No. 2, and the solutions were placed at 60-foot intervals in the field exposed to the sun.

RESULTS

No injury was observed for several weeks from any of the materials exposed in milk bottles. Little surface was exposed and temperatures in the dense shade were such that there was little evaporation of liquid over a period of several weeks. Six to eight plants surrounding material No. 1 later showed abnormal growth symptoms.

Two plants adjacent to the pan containing an "esterified" 2, 4-dichlorophenoxyacetic acid exposed directly to the sun showed severe effects within a week from the beginning of exposure. Abnormal growth symptoms gradually appeared in cotton plants in all directions from the pan until, when fully developed, abnormal plants occupied an area extending 25 to 30 feet in all directions from the center of exposure. In this experiment evaporation of liquid under the high temperatures of direct sunlight was rather rapid. Each abnormal plant was scored for injury on the basis of amount of fruit lost. In estimating the injury, an index of 10 was considered 100% injury, with the plant losing all fruit and later dying; an index of 5 equaled an estimated 50% fruit loss; 1 equaled 10% injury, with the plants losing approximately 10% of their fruit; and T equaled trace effects apparent in abnormal foliage but resulting in no visible loss of fruit.

Since there was no possible direct contact of the solution and affect-

ed plants, the injury could have been caused only by vapor. The general pattern of injury was very similar to that observed in commercial fields in that the greatest degree of injury occurred near the center of infection. Affected areas in farmers' fields usually extended a greater distance to the north than to the south of the center of exposure because the direction of prevailing winds in this area is from the south and southwest at this season of the year. The same effects were observed in this experiment. A summary of the number of injured plants, with the estimated injury index, is shown in Table 2.

TABLE 2.—*Summary of injury to cotton plants from exposure to volatile 2,4-D.*

Estimated injury index	Number of plants
10	2
9	0
8	4
7	16
6	11
5	20
4	11
3	32
2	37
1	71
T	169
Total	373

When it is considered that only 10 cc of a stock solution containing 9.6% active ingredient affected on volatilization a total of 373 plants, the high degree of volatility of the material, as well as the sensitivity of the plant, is emphasized.

The solution used in test No. 3 evaporated rapidly. Injury was noted from only one of the materials, that containing an "esterified" 2, 4-dichlorophenoxyacetic acid as an active ingredient. The injury developed in amount and extent similarly to that described above and followed the same general pattern.

DISTILLATION TESTS

MATERIALS AND METHODS

In order to supplement evaporation tests, a distillation test was used in which materials were diluted to weed spray strength and a portion of the material distilled in an ordinary laboratory distillation flask. One series of cotton plants in the field was then sprinkled with the distillate and another series with the undistilled residue.

RESULTS

The results of distillation tests are shown in Table 3. The distillate of material No. 1 appeared to be as toxic as the undistilled residue. When sprinkled on plants, distillate of this material volatilized and caused the typical abnormal growth symptoms to appear on plants in adjacent rows on each side of the treated row. The residue, while very toxic, did not volatilize, indicating that the active ingredient of this material is made up of two fractions, volatile and nonvolatile, or that

TABLE 3.—*Results of distillation tests of hormone spray materials, showing active ingredients and nature of distillate and residue.*

Material No.	Active ingredient	Date tested	Character of distillate	Character of residue
1	"Esterified" 2,-4dichlorophenoxyacetic acid	Aug. 3	Very toxic	Very toxic
2	Ammonium salt of 2,4-dichlorophenoxyacetic acid	Aug. 3	Nontoxic	Very toxic
3	2,4-dichlorophenoxyacetic acid	Aug. 3	Nontoxic	Very toxic
4	2,4-dichlorophenoxyacetic acid	Aug. 17	Nontoxic	Very toxic

it separates into two fractions on heating for distillation. None of the materials in which the active ingredient was known to be a salt of 2, 4-dichlorophenoxyacetic acid or the acid itself gave positive evidence of volatility either with the evaporation or the distillation test.

In several commercial fields, isolated abnormal cotton plants showing definite hormone effects were noted from 100 to 300 feet away from any other affected plants. These isolated affected plants occurred independent of the type of spray material used and cannot be explained on the basis of volatility. Some of them could not have been contaminated by irrigation water since there was no connected irrigation system. In these instances the method of transportation of the contaminating agent is not known. It is possible that drops of spray can be lifted by updrafts in air currents, carried for a distance, and then dropped; or that insects may carry the material to individual plants.

On the basis of field observation of some 20 affected spots of cotton in commercial fields, the following isolation would be needed when spraying weeds in midsummer with volatile materials:

Amount of diluted spray used	Isolation needed from cotton
1 quart	25 to 30 feet
1 gallon	50 to 100 feet
10 gallons	150 to 300 feet
50 gallons	300 to 500 feet
100 gallons	500 to 700 feet

SENSITIVITY OF THE COTTON PLANT

MATERIALS AND METHODS

To determine the amount of material which will produce effects when applied to an individual plant, a solution containing 1,000 p.p.m. of the ammonium salt of 2, 4-dichlorophenoxyacetic acid was applied to plants July 21 by pipetting measured amounts to the surface of the bottom, middle, or top leaves of separate plants and spreading the solution over the leaf surface. If more material was applied than could be held on the surface of one leaf, additional leaves were treated. Solutions applied to individual plants contained material equivalent to 1,000 p.p.m. active ingredient in dosages varying from 0.0001 to 0.5 cc in size.

To determine the concentration which will injure cotton plants when applied as a spray, the following spray concentrations in p.p.m. of the ammonium salt of 2, 4-dichlorophenoxyacetic acid were each applied July 13 to a 50-foot drill row,

thoroughly wetting the plants: 0.0001, 0.001, 0.01, 0.1, 1, and 10. Plants were about 18 inches tall at time of spraying and were beginning to flower rapidly. The effect on plants was measured by using the same injury index scale that was used for the volatility experiments.

RESULTS

The results of applications to individual plants expressed as an injury index on given dates are shown in Table 4.

TABLE 4.—*Results of application of hormone materials to bottom, middle, or top leaves of individual plants, expressed as an injury index on given dates.*

Amount 1,000 p.p.m. solution applied, cc	Applied on bottom leaves			Applied on middle leaves			Applied on top leaves		
	July 23	Aug. 1	Aug. 27	July 23	Aug. 1	Aug. 27	July 23	Aug. 1	Aug. 27
0.005	0	0	0	0	0	0	0	0	0
0.01	0	0	0	0	0	0	0	0	1
0.02	0	0	0	0	0	0	1	1	1
0.05	0	0	0	0	0	1	1	1	3
0.1	0	0	0	0	1	3	1	1	3
0.2	0	1	3	0	1	5	1	2	5
0.5	0	1	5	3	3	5	5	5	6

Smaller dosages than those shown in Table 4 produced no visible effects whatsoever. It is readily apparent from the data that the effect varied with the amount applied and that effects were more quickly evident when the material was applied to top leaves near the terminal growing point, with 0.01 cc of 1,000 p.p.m. solution being the minimum dosage causing injury.

When applied to entire plants as a spray, concentrations of 0.0001 to 0.1 p.p.m., inclusive, were not injurious. Results of spraying with 1 p.p.m. and 10 p.p.m. solutions are presented in Table 5.

TABLE 5.—*Effect of spraying cotton plants with 1 and 10 p.p.m. solutions of the ammonium acetate salt of 2,4-dichlorophenoxyacetic acid.*

Strength, p.p.m.	Number of plants sprayed	Number of plants affected	Average estimated injury index	Date first symptoms evident
1	55	55	1.3	July 23
10	49	49	8.6	July 14

Plants receiving a spray of 1 p.p.m. recovered and were producing normal foliage at the end of the season. Those receiving 10 p.p.m., or 1% of the strength normally used in spraying weeds, were unable to recover. Abnormal foliage was produced in the main and all lateral terminals for the remainder of the season and the plants were unable to fruit normally. Growth in plant height was almost normal, however, sprayed plants reaching an average height of 5 feet at the end of

the season as compared with 5½ feet in adjacent untreated rows. Affected leaves and fruit did not abscise but were apparently held tightly by the plant. Smaller dosages, however, produced no noticeable difference in normal shedding of fruit by plants.

SUMMARY AND CONCLUSIONS

Indiscriminate use of 2, 4–D or hormone type weed sprays in the 1945 season in southern New Mexico resulted in very abnormal growth of cotton in adjacent areas, the amount of injury depending on degree and time of contamination.

Materials used for the experiments presented herein were not absorbed from the ground surface or leached from dead weed tops to any extent by irrigation water. Observations on spray drift indicated that injury in commercial cotton fields extended over distances far too great to be explained by actual spray drift.

Evaporation and distillation tests indicated that tested materials known to contain an "esterified" 2, 4–dichlorophenoxyacetic acid were highly volatile when exposed directly to the sun in summer months, adjacent cotton plants being seriously injured by the vapor.

It is concluded that highly volatile materials or other formulae prepared in any manner that are highly conducive to transportation by air currents cannot be used safely during the summer months in intensive cotton growing areas such as those in southern New Mexico.

Materials containing unmodified 2, 4–dichlorophenoxyacetic acid or a salt thereof were nonvolatile and could be used with safety very close to cotton plants when care was taken to control actual spray drift.

The extreme sensitivity of the cotton plant is indicated by results showing that only 0.01 cc of solution containing 1,000 p.p.m. of ammonium salt of 2, 4–dichlorophenoxyacetic acid caused development of abnormal foliage on rapidly growing cotton plants in midseason. Degree of injury varied with amount applied, and symptoms were more quickly evident when applied to top than to bottom or middle leaves. When applied as a spray to entire plants, 1 p.p.m. caused injury from which plants recovered, while 10 p.p.m. caused serious injury and prevented normal fruit set; however, growth of the plant in height was almost normal.

EFFECT OF DDT UPON NODULATION OF LEGUMES[1]

M. D. APPLEMAN AND O. H. SEARS[2]

EXPERIMENTAL trials indicate that DDT is effective in controlling some insects harmful to crop plants. While the methods of use are in early experimental stages, it has been suggested that direct application to the soil may be feasible in the control of certain organisms such as soil nematodes; and for this reason it is important to know what chemical and biological effects DDT will have on the soil. If prescribed amounts prove toxic to soil microorganisms, certain biological processes may be retarded or inhibited.

The following investigations with legume nodule bacteria were conducted to determine whether DDT applied to the soil will prevent nodulation of legumes. Although the amount needed for insect control in the soil is not clearly defined, rates of application from 10 to 100 pounds an acre have been used. The experiments reported here were carried out in the greenhouse with two preparations of DDT, one a technically pure compound which contained approximately 98% DDT and the other, Neocid A 10, which contained 10% DDT in pyrophyllite. The preparations and directions for their use were furnished by Ralph Blanchard and C. M. Packard, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture.

EXPERIMENTAL

One-gallon stoneware jars were filled with 5,500 grams of sand to which $CaCO_3$ was added at the rate of approximately 5.0 grams to each jar. The technical DDT was applied at rates which represent 10, 100, and 1,000 pounds an acre when the total weight of sand in the jar is used as a basis for calculations; however, the DDT was mixed with the surface 2 inches only. Consequently, concentrations of 50, 500, and 5,000 pounds an acre actually existed in the surface 2 inches. Five jars for each rate, including untreated check, were set up, one each being planted with inoculated seeds of soybeans, peas, red clover, sweetclover, and lespedeza.

The emergence of red clover, sweetclover, and lespedeza was retarded only slightly in the presence of 1,000 pounds of DDT, while that of soybeans was noticeably delayed during the first 7 days by all concentrations (Table 1).

The height of the plants of all species tested was inversely proportional to the concentration of DDT (Fig. 1). A type of leaf deformity of soybeans grown in the presence of 1,000 pounds an acre of DDT is shown in Figs. 2 and 3.

At the end of 1 month the plants were washed from the jars and the roots examined for nodules. Plants grown in untreated sand and in sand treated with 10 pounds an acre of DDT showed tap-root nodulation (Fig. 4). Those grown in the presence of 100 pounds an

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication January 14, 1946.

[2]Assistant Professor and Professor in Soil Biology, respectively.

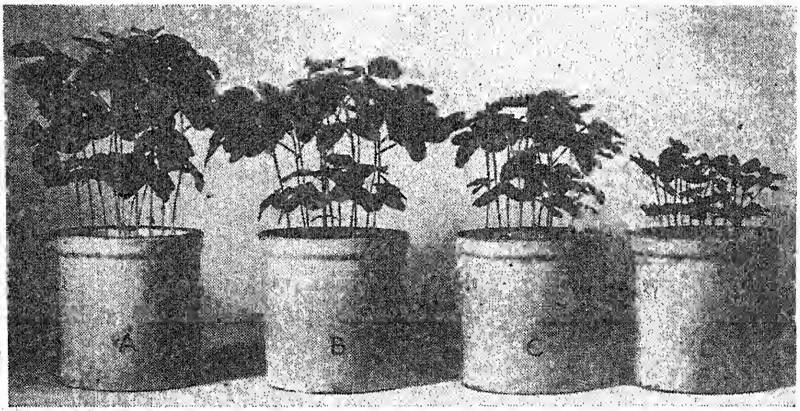

FIG. 1.—Inoculated soybeans grown in sand. Jars A, B, C, and D contain 0, 50, 500, and 5,000 pounds an acre, respectively, mixed in the surface 2 inches.

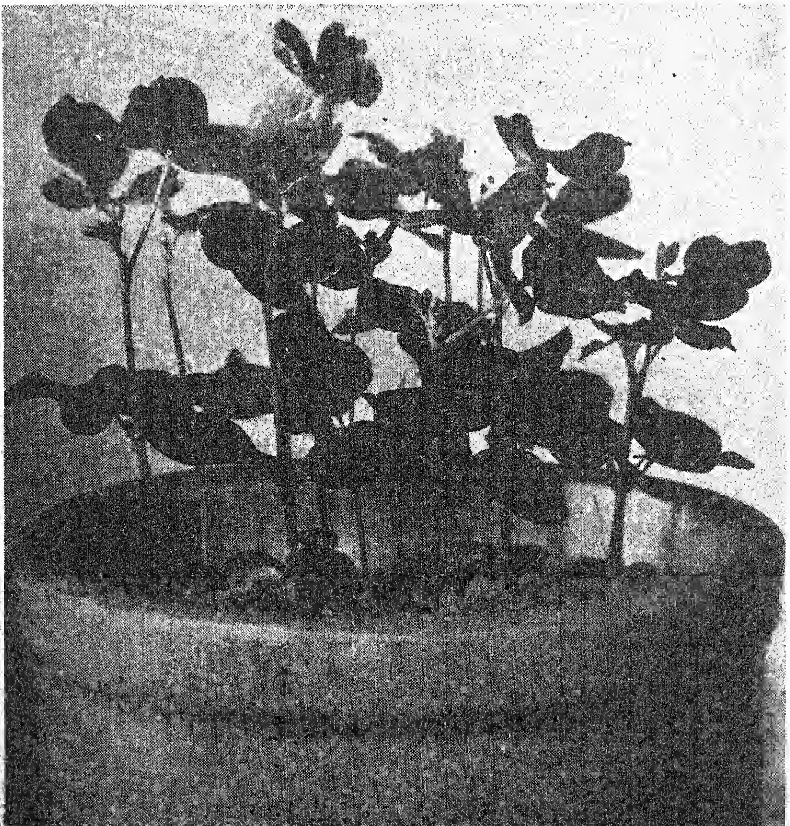

FIG. 2.—Plants in jar D, Fig. 1, showing deformity of upper leaves.

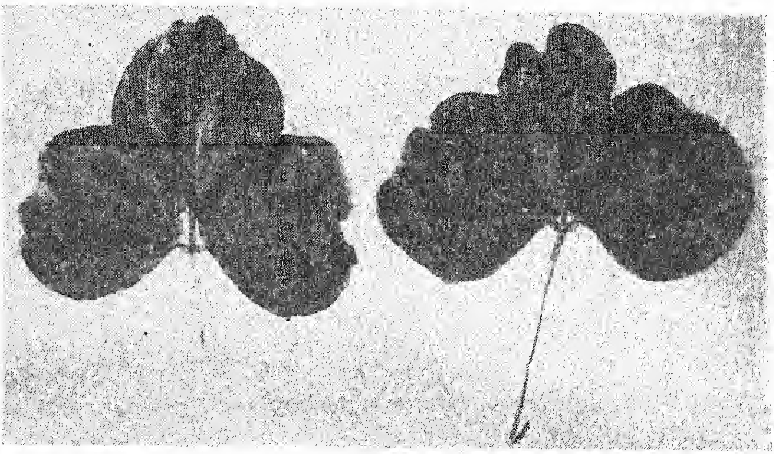

FIG. 3.—Leaves of plants in Fig. 2, showing typical deformity.

acre formed nodules below the treated zone, but not in the treated zone. Plants grown in the jars containing 1,000 pounds an acre produced very small nodules and the roots were severely injured. It is believed that these small nodules were a manifestation of late nodulation which did not begin until after the concentration of DDT had been reduced by leaching. The types of nodulation of peas were similar to those of soybeans.

TABLE 1.—*Effect of DDT upon germination and average height of inoculated soybeans grown in sand.**

DDT added, lbs. per acre	No. plants, May 5	No. plants, May 7	May 9		May 14		May 18		May 25	
			No. plants	Height, inches	No. plants	Height, inches	No. plants	Height, inches	No. plants	Height, inches
0	9	12	12	4.0	12	6.25	12	9	12	12
10	5	11	11	3.0	11	5.75	11	8	11	10
100	3	9	10	2.5	11	3.50	11	6	11	8
1,000	0	6	12	1.0	12	2.00	12	3.25	12	5

*12 seeds per jar planted May 1, 1945.

Since the results in the preliminary experiment were consistent enough to merit further investigation, another experiment was conducted in which inoculated legume seeds were planted in sand and also in soil treated with DDT using four replications of each treatment.

Ten per cent DDT applied at the rate of 10, 100, 1,000, and 10,000 pounds an acre was mixed throughout the sand, which was then saturated with nutrient solution containing all necessary elements for growth except nitrogen. Inoculated seed of sweetclover, red clover,

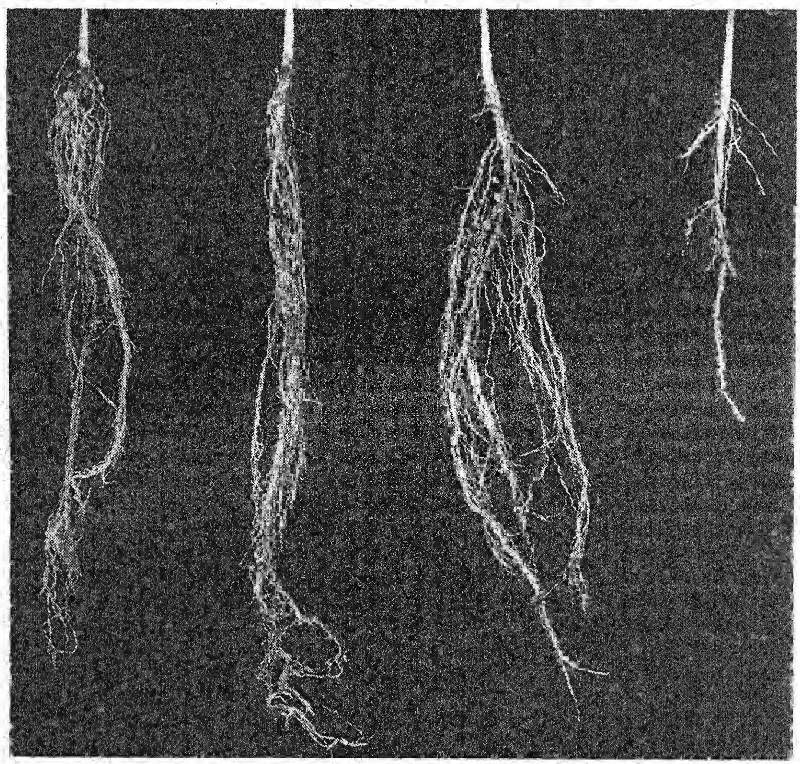

FIG. 4.—Roots of inoculated soybeans shown in Fig 1. Lateral root nodules formed below zone treated with 500 pounds per acre DDT.

FIG. 5.—Inoculated soybeans grown in sand. Jars A, B, C, D, and E contain 0, 10, 100, 1,000, and 10,000 pounds of 10% DDT an acre, respectively.

soybeans, and peas were planted in jars of treated sand. Each species was planted in separate jars at the rate of 50, 50, 8, and 8 seeds per jar, respectively.

Emergence of soybeans, peas, and red clover was slower in the sand jars containing the 10,000 pounds an acre application of DDT than in the control jars, or in those containing lighter applications. At the end of 10 days however, there was no marked difference in the number of plants emerged, but there was a difference in the height and maturity of the plants with the 1,000- and 10,000- pound treatments. Very few soybean plants in these series showed leaves at this time.

Fig. 5 shows the unfavorable reaction of soybeans to heavy applications of DDT. Similar results were secured with the other legumes tested. The decrease in size markedly influenced the dry weight of the harvested plants (Table 2). Root-hair injury was noted on all plants grown in the presence of either 1,000 or 10,000 pounds an acre of DDT, and red clover showed some visible root-hair injury also at 100 pounds an acre. The greater concentrations resulted in a decrease in the average number of nodules per plant.

TABLE 2.—*Effect of DDT upon inoculated legumes grown in sand.*

DDT, lbs. per acre	Number of seeds planted per jar	Average number of plants per jar	Average height per plant, in.	Average number of nodules per plant	Dry weight of 100 plants, grams		Total dry weight of 100 plants, grams
					Tops	Roots	
				Soybeans			
0	8	3.25	16.00	27.2	69.2	21.50	90.7
10	8	4.75	16.00	31.1	53.7	17.60	71.3
100	8	5.75	14.25	27.8	42.0	15.20	57.2
1,000	8	6.00	9.25	22.7	30.8	9.79	40.6
10.000	8	4.50	5.25	8.7	19.7	4.17	23.9
				Peas			
0	8	6.50	11.00	34.5	40.6	9.04	49.6
10	8	6.25	10.00	40.5	46.0	9.60	55.6
100	8	7.50	8.60	34.4	32.0	8.67	40.7
1,000	8	7.00	6.25	14.1	25.7	8.04	33.8
10,000	8	7.50	4.75	9.0	22.3	6.30	28.7
				Sweetclover			
0	50	31.25	5.25	11.1	3.5	1.0	4.1
10	50	31.75	4.75	10.0	2.5	0.2	2.7
100	50	33.25	4.13	9.3	2.2	0.7	2.9
1,000	50	35.25	3.75	4.3	1.1	0.2	1.3
10,000	50	24.75	3.25	4.1	0.7	0.1	0.8
				Red Clover			
0	50	41.50	4.00	8.6	1.5	0.7	2.3
10	50	42.25	3.75	8.6	1.0	0.2	1.2
100	50	36.00	2.88	6.8	0.3	0.1	0.4
1,000	50	31.22	1.13	5.6	0.1	0.1	0.2
10,000	50	26.50	0.75	4.9	0.1	0.1	0.2

No significant difference was noted in the nodulation or in the total weight of soybeans grown in soil to which the 10% DDT had been added (Table 3). No nodules were found on sweetclover plants grown in the presence of 10,000 pounds an acre of DDT, although there was only a slight difference in the height of these plants and those grown in jars containing smaller amounts. The 1,000- and 10,000-pounds per acre applications reacted unfavorably on nodulation of red clover.

TABLE 3.—*Effect of DDT upon inoculated legumes grown in soil.*

DDT, lbs. per acre	Number of seeds per jar	Average number of plants per jar	Average height per plant, in.	Average number of nodules per plant	Dry weight of 100 plants, grams		Total dry weight of 100 plants, grams
					Tops	Roots	
			Soybeans				
0	8	7.5	13.75	21.8	44.60	14.00	58.60
10	8	7.0	14.50	23.4	48.00	14.60	62.60
100	8	6.5	13.75	19.1	53.00	13.50	66.50
1,000	8	4.5	13.50	19.3	63.30	18.30	81.60
10,000	8	6.5	10.75	23.5	48.00	15.40	63.40
			Sweetclover				
0	50	24.0	3.87	2.5	2.08	0.31	2.39
10	50	20.0	4.12	2.0	1.13	0.25	1.38
100	50	25.0	4.25	1.0	1.50	0.20	1.70
1,000	50	16.0	4.37	2.5	2.50	0.25	2.75
10,000	50	13.5	3.12	0.0	1.30	0.26	1.56
			Red Clover				
0	50	31.5	3.37	6.0	1.83	0.16	1.99
10	50	36.0	3.25	9.4	0.90	0.14	1.04
100	50	25.0	3.60	8.3	1.60	0.20	1.80
1,000	50	35.0	2.85	3.5	1.29	0.11	1.40
10,000	50	17.5	2.25	1.1	1.00	0.20	1.20

DISCUSSION

Ten per cent DDT showed no inhibitory effect on the height of legumes grown in sand until the concentration reached 100 pounds an acre and it did not reduce nodulation until the concentration reached 1,000 pounds an acre. Plants grown in soil did not develop symptoms of injury to the same degree as those grown in the sand. This may have been due to the adsorption of DDT by the soil colloids.

Nodulation was adversely affected almost as much in the soil as in the sand. This may mean that the legume nodule bacteria themselves are damaged. Since root-hair injury was much less evident in soil than in sand, evidence seems to point to some inhibition of the legume nodule bacteria. Another indication that the bacteria are damaged was given in the first experiment in which nodulation was inhibited in the zone containing the chemical.

In no case were unfavorable results obtained in soil when treatment with DDT did not exceed 100 pounds an acre. It is not probable therefore that, when used at rates usually recommended, DDT will have an unfavorable effect on the nodulation of legumes.

EFFECTS OF FERTILIZERS ON YIELDS AND BREAKING STRENGTHS OF AMERICAN HEMP, *CANNABIS SATIVA*[1]

HOWARD V. JORDAN, A. L. LANG, AND GEORGE H. ENFIELD[2]

AMERICAN hemp, *Cannabis sativa*, became a strategic crop with the outbreak of war. Production was increased from a prewar average of about 2,000 acres to 175,000 acres in 1943, and approximately 62,000 acres were grown in 1944. The prewar production centered largely in Wisconsin and Kentucky; and the acreage was increased in those states as well as in Illinois, Indiana, Iowa, and Minnesota.

The experience of prewar producers served as a general guide to production practices, but widely differing soil and climatic conditions presented many problems in the newer areas. This stimulated considerable research in production and processing methods. This paper describes experiments in which the effects of fertilizers on yields and breaking strengths of hemp fiber were studied.

The fiber of American hemp is a bast fiber, or soft fiber, and it has many desirable characters. When well retted, it is soft and readily spinnable. Acre yields are about twice those of flax, which is the other principal domestic soft fiber. Another important quality of hemp is its high breaking strength. Since adequate harvesting machinery and processing facilities are now available these characters may permit hemp to retain a more important place among the domestic fibers than it occupied in the prewar period. Such a result may well be predicated on improvements in production and processing methods which will result in larger yields of better quality fiber.

LITERATURE REVIEWED

Studies dealing with the effects of fertilizers on the yields and quality of hemp fiber are largely of European origin. Herzog (5)[3] summarized the results of these studies and showed that yield responses varied with soil and climatic conditions. Herzog states that in general fiber from hemp grown on peat soils was inferior in strength to that grown on mineral soils. Various fertilizers were not consistent in their effects on quality of fiber. In general, however, soil conditions are said by Herzog to have less influence on strength of fiber than other factors, particularly maturity of the plant and the extent of fiber processing.

The literature relating to the effects of fertilizers on hemp as it was produced and handled in this country prior to 1942 is meager. Several papers dealing with this subject have appeared recently.

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[1]Joint contribution from the Division of Cotton and Other Fiber Crops and Diseases, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S. Dept. of Agriculture, in cooperation with the Wisconsin, Illinois, and Indiana Agricultural Experiment Stations. Received for publication January 24, 1946.

[2]Associate Soil Technologist, U. S. Dept. of Agriculture in cooperation with the Wisconsin Agricultural Experiment Station, Associate Chief in Soil Experiment Fields, Illinois Agricultural Experiment Station, and Assistant in Agronomy, Purdue Agricultural Extension Service. The authors are indebted to Dr. L. E. Hessler, Associate Chemist, Division of Cotton and Other Fiber Crops and Diseases, Lexington, Ky., for making all breaking-strength determinations, and to Dr. B. B. Robinson, Senior Agronomist, Division of Cotton and Other Fiber Crops and Diseases, and Prof. A. H. Wright, Department of Agronomy, University of Wisconsin, for helpful suggestions and advice.

[3]Figures in parenthesis refer to "Literature Cited", p. 563.

Chapman (3) obtained large increases in yield of hemp straw from complete fertilizers applied on the plowsole.

Wilsie, Black, and Aandahl (7) and Black and Vessel (1) reported on series of fertilizer experiments conducted in Iowa in 1943 and 1944. Nitrogen gave the largest increases in yield in both years, followed by phosphoric acid. The response to potash was in general small, with some responses negative and some positive. No studies on fiber quality were reported.

The Iowa experiments also included one on peat soil at Crystal Lake, Iowa. Some seedlings on this soil gained an early advantage and grew tall and coarse. These shaded out other plants which remained stunted and were of no value for fiber production. Increasing the seeding rate from the normal 5 pecks to 11 pecks per acre increased the stand of desirable plants by only 2.3 plants per square foot.

Studies of the effects of fertilizers on fiber flax are more numerous than those dealing with hemp. In view of the similarity of the two crops, certain of these studies may appropriately be considered in connection with the work reported here.

Tobler (8, 9) stressed the importance of anatomical studies of the bast cells of flax when studying the effect of fertilizers. He stated that the shape of these cells which influences the quality of the fiber has generally been attributed to herditary characters but is more likely to be the result of soil nutrients.

Bredemann and Fabian (2) and Fabian (4), also working with flax, found that a medium amount of nitrogen is desirable for the best quality and yield of fiber and that either a smaller or a larger application would produce less valuable results. A deficiency of nitrogen is conducive to the production of short fine stems containing little fiber, while abundant nitrogen tends to produce thick stems with lower fiber percentages and fiber of a low quality. With abundant nitrogen the fiber cells were lacking in uniformity and they had large lumens.

Miller, Burton, and Manning (6) found that as flax stems increased in diameter the number of fibers, the number of bundles, and the number of fibers per bundle also increased. However, large stems had fewer fibers per unit of area than the small stems, and the individual fibers were coarser.

EXPERIMENTAL

Series of fertilizer experiments were conducted on mineral soils in Wisconsin and Illinois in 1943 and 1944. These experiments were uniformly arranged in factorial designs, thus permitting isolation of the effects of each fertilizer constituent and of the interactions among them. Other experiments in Indiana, and on peat soil at Coddington, Wis., followed different plans.

The hemp straw from each plot was dew retted, and, except for the experiment at Ladd, Ill., in 1944, the fiber was separated on a small reciprocating brake. The hemp straw from the experiment at Ladd, Ill., was processed in a commercial mill at that location. All tests of breaking strength were made on a Scott tester using spool clamps. The sample tested comprised fiber strands 25 cm in length, 0.2 to 0.7 gram in weight, and conditioned at 66% humidity. The breaking distance between centers of clamps was 7.5 cm.

EXPERIMENTS IN WISCONSIN AND ILLINOIS IN 1943

There were five experiments in this series in 1943. They were located on fields in relatively good state of fertility which were considered well adapted to hemp. All but one had been manured or had grown legumes or sod crops in recent years. Details of location, soil type, and cropping history are given in the first part of Table 1.

Nitrogen, phosphoric acid, and potash were applied, each singly and in all possible combinations, and the combined application was equivalent to a 3–12–12 analysis at 300 pounds per acre. Fertilizers

were broadcast and disced in shortly prior to seeding hemp. There were five or six replications in each experiment. The data were treated by analysis of variance and are summarized in Table 2.

Mean yields of fiber ranged from satisfactory to quite high, and the increases due to fertilizer were moderate. It seems probable that the fields selected, by reason of good past management, were able to produce quite satisfactory hemp crops on the unfertilized plots. An exception should be noted in case of the Canniff field which was in hemp for the third successive year, and where fertilizer applications, particularly of nitrogen, were probably inadequate for maximum yields. Such increases as occurred were caused principally by nitrogen.

In all of the experiments, except that on the Canniff farm, the breaking strength of fiber from nitrogen-treated plots was lower than that from no-nitrogen plots. In two cases the reductions due to nitrogen were highly significant, and amounted to 7.3 and 9.5%, respectively. When the data were pooled and analyzed collectively, as shown in Table 3, there was a highly significant reduction in breaking strength caused by nitrogen which amounted to 4.4%. Omitting the data from the Canniff experiment, the mean reduction in breaking strength was 5.7%.

This effect was produced by only 9 pounds of nitrogen per acre. Because of the relatively good state of fertility prevailing on most of the fields, it is possible that this may have provided for more nitrogen than was needed in the early growth stages. If this is the case, it is indicated that even moderately excessive nitrogen applications may prove detrimental to the quality of hemp fiber.

In four of the five experiments the breaking strength of fiber from phosphate-treated plots was greater than that from no-phosphate plots although differences were not significant in any case. When the data were analyzed collectively (Table 3), there was an indicated significant increase in breaking strength caused by phosphoric acid. Potash did not affect breaking strength in any individual experiment nor in the experiments as a group.

EXPERIMENTS IN WISCONSIN AND ILLINOIS IN 1944

There were four experiments in the series of 1944, and by design the fields included a range in cropping histories and adaptability to hemp. Details of location, soil type, and cropping history are given in the second part of Table 1. The two fields listed first were in timothy sod the previous year, and they were spring plowed. Such a sequence is particularly unsuited to hemp with its high requirement for available nitrogen. The two other fields had grown legume crops in recent years and corresponded more nearly in fertility level to the fields used in 1943.

Fertilizers were applied as in 1943 in a factorial scheme, utilizing 0, 50, and 100 pounds of nitrogen, 0, and 30 pounds of phosphoric acid, and 0, and 20 pounds of potash per acre. There were four replications in each of the experiments in Wisconsin and two replications in the experiment on War Hemp Industries' field at Ladd, Ill. The data of the experiments are summarized in Table 4.

TABLE 1.—*Location, soil type, and cropping history of fields used for fertilizer experiments with hemp in 1943 and 1944.*

Name of cooperator	Location of field	Soil type	Cropping history
		1943 Fields	
W. Virchow	De Forest, Wis.	Carrington silt loam	Sweetclover, 1941; sweet corn, 1942
E. Keel	Juneau, Wis.	Miami silt loam	Corn, 1942; manured for hemp
R. Canniff	Beaver Dam, Wis.	Carrington silt loam	Hemp, 1941, 1942, and 1943
H. Newcomer	Mt. Morris, Ill.	Tama silt loam	Sweetclover, 1941; corn, 1942
H. Donaldson	Polo, Ill.	Tama silt loam	Sod to 1941; corn, 1942
		1944 Fields	
L. Wedig	Cuba City, Wis.	Dodgeville silt loam	Meadow, 1940–43; mostly timothy, 1942–43
War hemp industries	Ladd, Ill.	Tama silt loam	Meadow for years, mostly timothy
Wis. Exp. Station	Madison, Wis.	Miami silt loam	Legume-grass pasture, 1942; corn, 1943
P. Walsh	De Forest, Wis.	Clyde silt loam	Alfalfa, 1941; corn, 1942–43

TABLE 2.—*Effects of fertilizers on yields and breaking strengths of hemp fiber, experiments in Wisconsin and Illinois, 1943.*

Name of cooperator	Acre yield of fiber, pounds							Breaking strength of fiber, kgms per gram						
	Nitrogen		Phosphate		Potash		Mean	Nitrogen		Phosphate		Potash		Mean
	Present	Absent	Present	Absent	Present	Absent		Present	Absent	Present	Absent	Present	Absent	
W. Virchow	2,248	2,126	2,224	2,150	2,222	2,152	2,187	121.1	122.9	124.9	119.2	120.9	123.2	122.0
E. Keel	1,921	2,013	1,943	1,991	1,980	1,954	1,967	141.2**	152.4	149.5	144.1	147.7	146.0	146.8
R. Canniff	1,316	1,210	1,271	1,256	1,265	1,262	1,263	177.3	176.0	177.4	175.9	177.5	175.8	176.7
H. Newcomer	1,581	1,526	1,558	1,549	1,527	1,580	1,553	132.1**	145.9	138.4	139.5	141.5	136.4	139.0
H. Donaldson	1,489	1,462	1,498	1,453	1,472	1,478	1,475	135.8	141.4	141.0	136.2	138.9	138.3	138.6
Mean	1,711	1,667	1,699	1,680	1,693	1,685	1,689	140.2**	146.6	145.0*	141.8	144.1	142.7	143.4

*Differs from corresponding no treatment, $P = 0.05$.
**Differs from corresponding no treatment, $P = 0.01$.

TABLE 3.—*Analysis of variance for breaking strength of hemp fiber from five experiments in Wisconsin and Illinois.*

Source	DF	Variance	F value
Total	2,239	—	—
Experiments	4	171,735.23	121.99**
Blocks	23	2,559.17	1.82*
Treatments:			
N	1	22,348.79	15.87**
P	1	6,010.28	4.27*
K	1	1,049.69	—
NP	1	590.81	—
NK	1	334.65	—
PK	1	0.19	—
NPK	1	36.11	—
Exp.×treatments	28	1,203.24	—
Error	161	1,407.81	—
Sampling error†	2,016	742.60	—

*Significant, P = 0.05.
**Significant, P = 0.01.
†Ten determinations of breaking strength were made on the fiber from each plot. The sampling error is a measure of the composite variance among these determinations.

On the Wedig and War Hemp Industries' fields, where hemp followed spring-plowed timothy sod, the unfertilized hemp exhibited marked nitrogen deficiency. On both of these fields there were large and highly significant increases in yield from applied nitrogen, and the Wedig field responded to phosphoric acid as well. Inasmuch as yields increased progressively through the 0-, 50-, and 100-pound nitrogen applications, and as judged by yields and appearance of the crop with the heaviest treatment, it is doubtful if nitrogen at 100 pounds per acre more than met the requirements for satisfactory yields. Under these conditions no fertilizer element tested significantly affected the breaking strength of fiber.

The general character of growth on the Wedig field is shown in Fig. 1, and that on War Hemp Industries' field in Fig. 2.

On fields of the Wisconsin Experiment Station and the Walsh farm, fiber yields were not increased significantly by the nitrogen additions, while the Walsh field responded to application of phosphoric acid. It is probable that the treatments supplied more nitrogen than was needed for maximum fiber production. This is supported by data on losses in retting. On the Wisconsin Experiment Station field losses from green weight (calculated to dry basis) to dry-retted straw amounted to 17.0, 18.8, and 20.5% for the 0-, 50-, and 100-pound nitrogen additions, respectively. Corresponding figures on the Walsh field were 24.0, 26.6, and 30.2%. These figures represent losses of leaves in part, but they also reflect the generally more succulent type of growth on the niitrogen-treated plots. Linear trends in both cases were highly significant.

On both of these fields hemp fertilized with nitrogen at 100 pounds per acre had lower breaking strength than the hemp without nitrogen. The reduction on the Wisconsin Experiment Station field approached significance and on the Walsh field the difference was highly significant. Collective analysis of variance of the data from the two fields

TABLE 4.—*Effects of fertilizers on yields and breaking strengths of hemp fiber, experiments in Wisconsin and Illinois, 1944.*

Name of cooperator	Acre yields of fiber, lbs.								Breaking strength of fiber, kgms per gram							
	Nitrogen			Phosphate		Potash		Mean	Nitrogen			Phosphate		Potash		Mean
	0	50	100	0	30	0	20		0	50	100	0	30	0	20	
L. Wedig....	300	785*	900**	562	772**	600	734	667	98.7	98.7	91.7	95.5	97.3	92.8	100.0	96.4
War Hemp Ind.......	505	596	862**	626	683	700	609	655	80.6	88.4	82.7	84.5	83.3	82.3	85.5	83.9
Wis. A.E.S...	1,397	1,489	1,397	1,435	1,420	1,382	1,473	1,429	110.5	112.8	98.1	105.5	108.7	104.2	110.1	107.1
P. Walsh....	1,137	1,191	1,115	1,092	1,206*	1,122	1,176	1,149	127.7	113.4	105.0**	114.9	115.9	117.7	113.1	115.4

*Differs from corresponding no treatment, P = 0.05.
**Differs from corresponding no treatment, P = 0.01.

shows a highly significant linear reduction in breaking strength due to the nitrogen applied. For the 100-pound application this amounted to 14.7%.

Nitrogen applications in the 1944 experiments were associated with general increases in stem diameter, although these were not large in all cases. In the experiment on the Wedig farm, mean stem diameters above the 0-, 50-, and 100-pound nitrogen treatments were 3.6, 4.7,

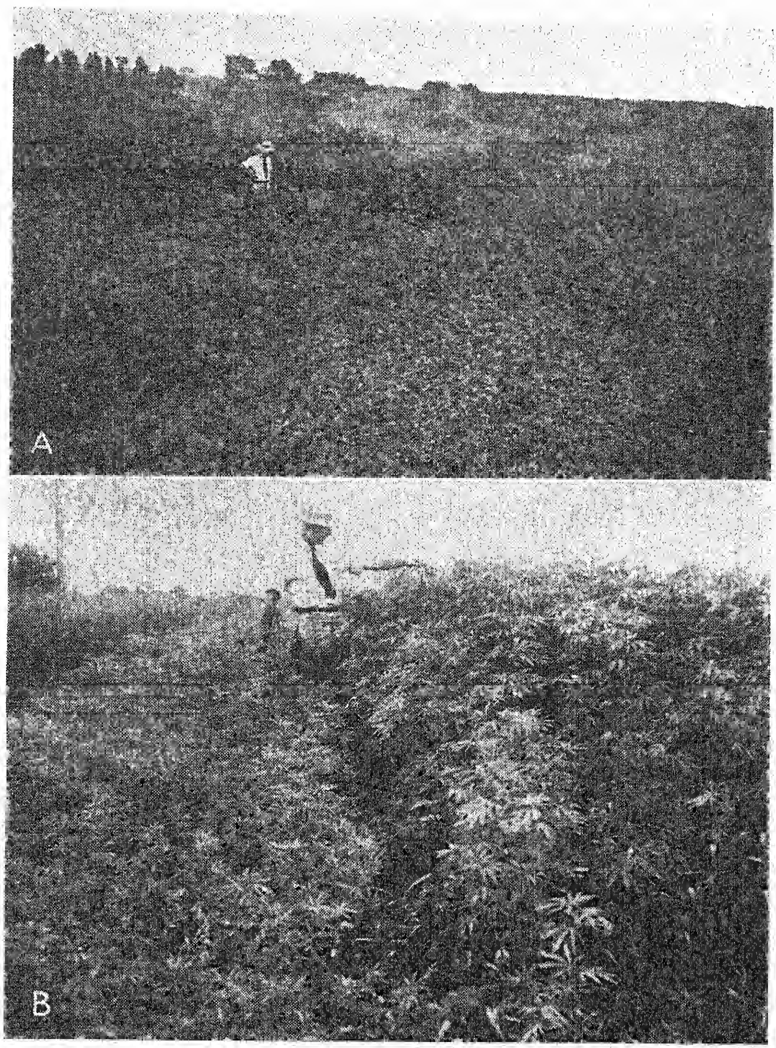

FIG. 1.—A, general character of growth of hemp on field on the Wedig farm adjoining experimental plots. B, experimental plots on the Wedig farm. *Right*, 100–30–0; *left*, 0–0–0.

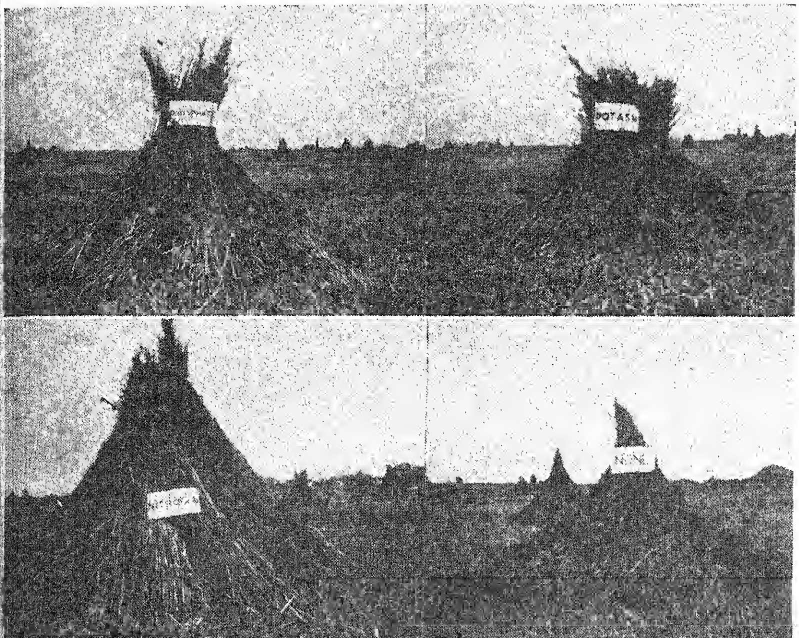

FIG. 2.—Shocks of retted hemp from equal areas of the experiment on War Hemp Industries' field at Ladd, Ill., showing the effects of fertilizers. *Upper left*, 0–30–0; *upper right*, 0–0–20; *lower left*, 100–0–0; *lower right*, 0–0–0.

and 5.1 mms, respectively. Corresponding data are not available for the experiment on War Hemp Industries' field, but stems sizes are known to vary in a similar manner. The lower dimension is too fine for most desirable hemp, while the upper limit is within the optimum range. On the other two fields, which were in better state of fertility, mean stem diameters of the unfertilized hemp were approximately equal to the maximum diameter of hemp on the Wedig experiment, and there were small additional increases as nitrogen was applied. This suggests that declining levels of breaking strength may be associated in part with stem diameters above the optimum range.

In most cases breaking strength of fiber was greater where phosphoric acid and potash were applied than where these minerals were not used, but differences were small and in no case significant.

Mean breaking strength of fiber from the 1944 experiments was lower than that from the 1943 experiments. This is probably the result of differences in conditions for growth or retting of the respective crops, and no explanation is advanced. Breaking-strength values within any given experiments are comparable because all plots were handled alike, although differences in composition induced by variable fertilizer treatments may have affected the character of retting. Comparisons between experiments may not be fully justified because of differences in times of harvest and exposure for dew retting.

EXPERIMENTS IN INDIANA

Four fertilizer experiments with hemp were conducted in Indiana in 1943. These were located on farmers' fields which had already received blanket applications of fertilizer. Details of location, soil type, and blanket fertilizer application are given in Table 5.

Experimental treatments including (a) no treatment, (b) 8–8–8 fertilizer at 500 pounds per acre, and (c) 8–8–8 fertilizer at 1,000 pounds per acre were superimposed on these fields. The treatments were made as surface applications shortly prior or subsequent to the time of seeding hemp. Data are recorded in Table 6.

In each case, as the fertilizer rate was increased, the stalks developed taller and coarser, and there were large increases in yield. In three of the experiments there was a progressive reduction in breaking strength of fiber with increasing fertilizer additions. There was one exception to this trend in the experiment on the Stevens farm. Here the fertilized plots produced stronger fiber than those without fertilizer, but as in the other experiments, the fiber was weaker where fertilized with 1,000 pounds than where 500 pounds per acre were applied. It is noteworthy in this connection that the unfertilized hemp on the Stevens field was exceptional in another respect. It attained an average height of only 3.5 feet, produced only 846 pounds of fiber per acre, and was a virtual crop failure.

Mean reductions in breaking strength in these experiments amounted to 1.4% for fertilizer at the lower rate and to 11.1% for the heavier application. Fiber from the fertilized plots was coarse, and this was particularly true with the heavy applications.

TABLE 5.—*Location, soil type, and blanket fertilizer applications on fields used for fertilizer experiments with hemp in Indiana in 1943.*

Name of cooperator	Location of field	Soil type	Blanket fertilizer application	
			Analysis	Acre rate, lbs.
Von Crow.....	Markle	Miami silt loam	3–12–12	350
Howard Bonham........	Warren	Miami-Crosby silt loam	2–12–6	300
George Spencer	Monticello	Parr loam	3–9–18	350
Jerry Stevens..	Remington	Carrington silt loam	3–12–12	250

While it is not possible in the Indiana experiments to attribute the reduction in breaking strength to any particular fertilizer constituent, it is perhaps pertinent that the heavier application supplied nitrogen at 80 pounds per acre. The methods of application should provide for more effective utilization of nitrogen than of the mineral elements of the fertilizer. Accordingly, it is a plausible assumption that the nitrogen of the 8–8–8 fertilizer was an important factor in reducing fiber strength in these experiments also.

TABLE 6.—*Effects of fertilizers on plant measurements, yields, and breaking strengths of hemp grown in experiments in Indiana, 1943.*

Name of cooperator	Method of fertilizer application	Acre rate of 8–8–8 fertilizer, lbs.	Number of replications	Plant measurements		Acre yields, lbs.		Breaking strengths, kgms per gram
				Height, ft.	Diameter, mm*	Retted straw	fiber	
Von Crow	Top dressed after seeding hemp	0	5	7.0	7.1	6,400	1,556	114.7
		500		7.7	6.3	7,100	1,755	109.2
		1,000		8.0	8.7	7,700	1,879	101.1
Howard Bonham	Broadcast on surface and disced in prior to seeding hemp	0	5	5.7	—†	5,220	1,381	110.1
		500		7.0	—†	7,480	1,630	100.8
		1,000		7.5	—†	8,520	2,315	87.6
George Spencer	Broadcast on surface and disced in prior to seeding hemp	0	3	4.5	4.0	4,660	1,452	111.6
		500		7.0	5.5	8,100	2,232	110.3
		1,000		8.0	7.1	8,620	2,178	103.5
Jerry Stevens	Top dressed after seeding hemp	0	3	3.5	4.0	3,560	846	111.7
		500		6.2	5.5	6,180	1,493	129.3
		1,000		7.0	7.1	7,480	1,829	113.6
Mean		0		5.5	5.4	5,173	1,349	112.1
		500		7.1	5.9	7,234	1,756	110.6
		1,000		7.7	7.8	8,088	2,062	99.7

*Measured 1 foot from butt ends.
†Not measured but known to increase with increase in fertilizer application.

EXPERIMENTS ON PEAT SOIL AT CODDINGTON EXPERIMENT FARM[4]

It is well recognized that hemp fiber produced on marsh soils is weak, and such soils are not recommended for hemp production. Marsh soils are characterized by their high content of nitrogen, and it was postulated that this might be at least partly responsible for the poor quality. Characteristically, hemp on these soils "thins itself out"; that is, some plants grow tall and coarse, while others, due to shading and competition, produce only short stunted stems. Hemp behaves similarly on mineral soils at high nitrogen levels, notably on old barnyards, feeding lots, etc.

In an experiment on peat soil at Coddington, Wis., in 1943, an abundance of phosphoric acid and potash was supplied in an effort to balance the nitrogen level. Fertilizers of 0-10-20, 0-20-20, and 0-10-30 analyses were applied at rates ranging from 500 to 2,000 pounds per acre. The hemp produced well with yields ranging from 1,780 to 2,265 pounds of total fiber per acre and averaging 2,053 pounds. However, the fiber had poor quality and its mean breaking strength was only 104.0 kilograms per gram. This compares with a mean breaking strength of 143.4 kilograms per gram for the fiber grown in experiments on mineral soils in Wisconsin and Illinois during the same year.

For the 1944 experiment, also at Coddington, treatments were designed to reduce the available nitrogen level as well as to supply minerals. A heavy sod of reed canary grass was plowed in late spring to raise the effective C:N ratio. Chopped straw was disced in on certain plots at 4,000 and 8,000 pounds per acre, respectively, to accentuate this effect further. Hemp was seeded the following day, thus insuring that the seedling stage of growth would coincide with active decomposition of this carbonaceous material. Except on unfertilized plots, the hemp received a blanket application of 2-10-20 fertilizer at 1,000 pounds per acre at time of seeding. Various minor elements were applied on duplicate plots, but since none of these had a consistent effect on yields or quality of fiber, the results are not reported in detail.

The essential data of the 1944 experiment are summarized in Table 7. The hemp made only moderate growth and showed evidence of nitrogen deficiency. Nitrogen deficiency was accentuated by the straw treatments, particularly the heavier rate. Stem diameters ranged from desirable diameters to too fine, and there was no selective self-thinning.

The mean yield on fertilized plots following spring-plowed reed canary grass sod was 1,113 pounds of fiber per acre and its mean breaking strength was 147.1 kilograms per gram. This yield, while reasonably satisfactory, was only a little more than one-half of the 1943 yield, but the fiber was of good quality. Its breaking strength was superior to that of hemp grown on mineral soils in any experiment in 1944 and to the mean breaking strength of fiber produced in the experiments of 1943. Straw at 4,000 pounds per acre depressed

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[4]Collaboration by A. R. Albert, Superintendent, Branch Experiment Station, Coddington, Wis., in this phase of the work is gratefully acknowledged.

the yield only slightly and the fiber was of good quality, but straw at 8,000 pounds per acre proved excessive.

TABLE 7.—*Plant measurements, yields, and breaking strengths of hemp grown on pea soil at Coddington, Wis., in 1944, following spring-plowed reed canary grass sod.*

Treatment	Plant measurements		Acre yields, lbs.		Breaking strengths, kgms per gram
	Height, in.	Diameter, mm	Retted straw	Fiber	
No fertilizer	57.5	4.2	4,673	1,012	156.7
2–10–20	62.8	4.7	5,791	1,113	147.1
Straw+2–10–20:					
4,000 lbs. per acre	64.0	4.4	5,924	1,032	145.3
8,000 lbs. per acre	50.0	3.2	2,850	388	138.3

This experiment was exploratory, and hemp was not grown concurrently in other cropping sequences. Thus the results cannot be regarded as conclusive; nevertheless, the character of growth and quality of fiber were widely different from those usually obtained on marsh soils.

DISCUSSION AND SUMMARY

There was little information regarding the effects of fertilizers on yields and quality of hemp fiber as produced in this country prior to 1943 when the acreage was greatly expanded. Research with flax indicated that abundant nitrogen might lower the quality of that fiber.

A series of fertilizer experiments with hemp was begun in Wisconsin and Illinois in 1943. The soils were in good state of fertility and responded only moderately to fertilizers. Nitrogen at 9 pounds per acre reduced the mean breaking strength of fiber by 4.4%.

The experiments of 1944 included two which responded markedly to nitrogen and two which gave no response. On the former fields nitrogen did not significantly reduce breaking strength, but on the latter nitrogen at 100 pounds per acre caused a mean reduction of 14.7% in breaking strength of fiber.

In experiments in Indiana increasing the application of 8–8–8 fertilizer through 0,500, and 1,000 pounds per acre increased the yield and caused general progressive reductions in breaking strength of fiber. For the 1,000-pound rate the reduction amounted to an average of 11.1%.

In an experiment on peat soil in 1943 heavy applications of mineral fertilizers produced high yields, but the fiber was of poor quality. In 1944, the level of available nitrogen was reduced by spring plowing a sod and applications of carbonaceous materials, and minerals were applied. The yield was only moderate but the fiber had good quality and breaking strength.

Abundant nitrogen causes a more leafy and succulent type of growth in hemp, and tends to increase stem diameter above the optimum range. These characters were associated with lower breaking strength of fiber in these experiments.

Hemp makes a rapid growth, and adequate supplies of available nitrogen are essential for satisfactory crops. However, these data indicate clearly that excessive applications should be avoided. The problem is one of adjusting rates and balances of nutrients in such a way as to assure maximum production and at the same time maintain fiber quality. From the point of view of the grower, some loss in fiber strength may be justified if the increased yields give a greater net income.

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NOTES

USE OF THE NATURAL CROSSING PLOT IN MAKING CASTOR BEAN HYBRIDS

SEVERAL years' observations and studies on the growth and floral habits of the castor bean plant led to the idea that the use of the natural crossing plot might be practical for making hybrid seed. First, the plant is mainly wind-pollinated. Second, the staminate flowers are easily removed before they shed pollen. The inflorescence consists of a spike bearing pistilate flowers on the upper portion and staminate flowers on the lower portion. In most cases the area of the spike bearing pistilate flowers is clearly differentiated from the area bearing staminate flowers. In a few types there is not this distinct separation, and in extreme cases, the staminate flowers are borne throughout the spike. Although these exceptional types make removal of staminate flowers somewhat tedious and time-consuming, they do not render the method impractical. Finally, the plants are indeterminate in growth habit. Flowers are produced throughout the growing season, and the period over which pollen is shed is therefore prolonged.

To test the feasibility of making castor bean hybrids in natural crossing plots, experiments were conducted in 1944 and 1945 at the Illinois Agricultural Experiment Station. The technic was similar to

that used for making single crosses of corn, except that the pollen and seed parents were planted in alternate rows. The pollen parent was planted in each outside row as well as in alternate rows, but not across the ends of the rows.

Small plots were used consisting of 10 to 14 rows 40 inches apart and 2 rods long. Plants in both male and female rows were spaced 20 inches apart. Production of a good supply of viable seed was an indication of an adequate supply of pollen.

Isolation was obtained by spotting the plots in a corn field (Fig. 1). Plantings separated by as little distance as 10 rods showed no evidence of out-crossing.

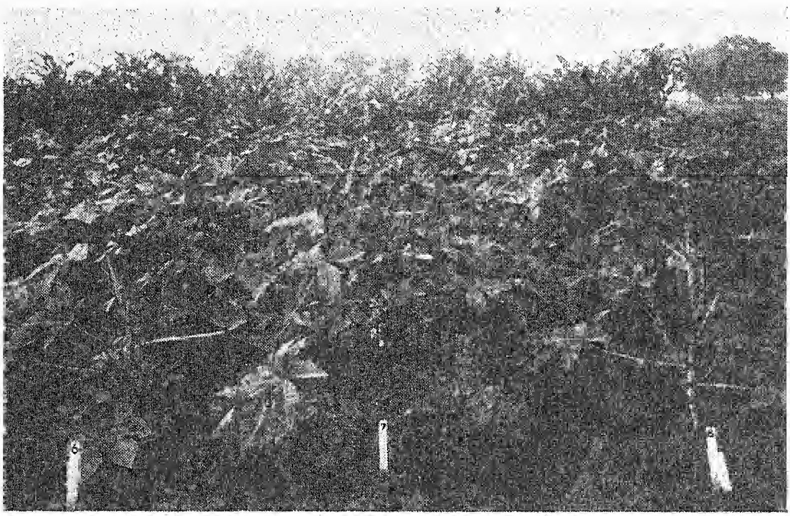

FIG. 1.—Portion of a castor bean natural crossing plot located in a corner of a corn field. Rows 6 and 8 are seed parent rows. Row 7 is a pollen parent row.

Emasculation consisted in removing the staminate flowers from the spikes before they shed pollen. This was accomplished in two ways. One way was to rub off the flowers with the thumb or fingers. This method was found satisfactory on large spikes with clearly differentiated staminate flowers. On small spikes it was found difficult to do this without injuring them. The second and more satisfactory method was to use a medium size forceps. By a combination of pinching and pulling, the staminate flowers were easily removed without injuring the spike.

Emasculation required at least two visits to each spike. When growing conditions were ideal, and the plants were in the height of flowering, the plot had to be examined every other day to insure that all staminate flowers were removed before they shed pollen. In plots where there were several seed parents differing widely in time of flowering, the emasculation process lasted several weeks. However, as soon as sufficient seed was formed on any given seed parent, all later

formed spikes were removed. When the seed was mature, the pods were harvested, and the plants pulled or cut down.

So far as the authors know, this is the first instance of the use of the natural crossing plot for making castor bean hybrid seed. White[1] suggested a simple rapid method of hand pollination as follows: "Plants of the two types to be crossed could be grown separately and one lot used entirely as a pollenizer. A large quantity of pollen from the same spike matures at the same time. Hence, these spikes could be cut off when nearly mature, and laid on paper sheet still the pollen was shed —a matter of a day or two. The pollen could then be collected in a powder gun or similar device and shot over the newly matured pistils each morning. The male flowers on the plants used as seed-bearers, for the most part, can be easily rubbed off without injuring the flower spike. The amount of selfed seed by this method could be very small, most of the mature seed being crossed."

Since, under growing conditions at the Brooklyn Botanic Gardens, White[2] found only 5% or less of natural crossing in castor beans, he likely thought that pollen was not distributed well enough naturally to make hybrid seed; hence, his reliance on collecting and applying pollen by hand. In contrast, under Illinois conditions, Domingo[3] found 36% crossing between adjacent plants in the same row and between plants in adjacent rows. The difference in amount of natural crossing at these two locations was probably due to greater air movement at Urbana.

Hybridizing castor beans by hand is laborious and time-consuming, and requires considerable care to insure complete emasculation and satisfactory pollination. Furthermore, Alternaria infection is quite likely to result from the high humidity under the bag and from injury to the spike during emasculation. The developing embryos may be completely destroyed by this fungus, while unmolested flowers develop normally unless conditions are such that heavy infection with Alternaria takes place in the entire nursery.

The natural crossing plot furnishes a means of producing large amounts of seed of a given cross. It is useful, therefore, in making varietal crosses, top-crosses for testing inbred lines, and back-crosses. Where isolation is complete and emasculation is thorough, seed produced on the male parent rows is pure seed of that line. If through breeding, inbred lines or strains are developed which gives significant increases in yield when crossed, the natural crossing plot provides a method of producing crossed seed in quantity at relatively little expense.—R. O. WEIBEL AND C. M. WOODWORTH, *Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill.*

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UNIVERSAL YIELD DIAGRAM TABLE

THE usefulness of the universal yield diagram or curve as calculated by the Mitscherlich-Baule yield equation, log (A-y) equals log A – 0.301x, has been explained and emphasized by Dr. O. W. Willcox

*Yield values expressed as percentages of A for values of X in the universal yield diagram.**

X.XX	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.00	0.69	1.38	2.06	2.73	3.41	4.07	4.74	5.39	6.05
0.1	6.70	7.34	7.98	8.62	9.25	9.88	10.50	11.12	11.73	12.34
0.2	12.94	13.55	14.14	14.74	15.33	15.91	16.49	17.07	17.64	18.21
0.3	18.77	19.34	19.89	20.45	21.00	21.54	22.08	22.62	23.16	23.69
0.4	24.21	24.74	25.26	25.77	26.29	26.80	27.30	27.80	28.30	28.80
0.5	29.29	29.78	30.26	30.74	31.22	31.70	32.17	32.64	33.10	33.57
0.6	34.02	34.48	34.93	35.38	35.83	36.27	36.71	37.15	37.58	38.01
0.7	38.44	38.87	39.29	39.71	40.13	40.54	40.95	41.36	41.76	42.17
0.8	42.57	42.96	43.36	43.75	44.14	44.52	44.90	45.29	45.66	46.04
0.9	46.41	46.78	47.15	47.51	47.88	48.24	48.59	48.95	49.30	49.65
1.0	50.00	50.35	50.69	51.03	51.37	51.70	52.04	52.37	52.70	53.02
1.1	53.35	53.67	53.99	54.31	54.62	54.94	55.25	55.56	55.86	56.17
1.2	56.47	56.77	57.07	57.37	57.66	57.96	58.25	58.53	58.82	59.10
1.3	59.39	59.67	59.95	60.22	60.50	60.77	61.04	61.31	61.58	61.84
1.4	62.11	62.37	62.63	62.89	63.14	63.40	63.65	63.90	64.15	64.40
1.5	64.64	64.89	65.13	65.37	65.61	65.85	66.08	66.32	66.55	66.78
1.6	67.01	67.24	67.47	67.69	67.91	68.14	68.36	68.57	68.79	69.01
1.7	69.22	69.43	69.65	69.85	70.06	70.27	70.48	70.68	70.88	71.08
1.8	71.28	71.48	71.68	71.87	72.07	72.26	72.45	72.64	72.83	73.02
1.9	73.21	73.39	73.57	73.76	73.94	74.12	74.30	74.47	74.65	74.83
2.0	75.00	75.17	75.34	75.51	75.68	75.85	76.02	76.18	76.35	76.51
2.1	76.67	76.83	76.95	77.15	77.31	77.47	77.62	77.78	77.93	78.08
2.2	78.24	78.39	78.54	78.68	78.83	78.98	79.12	79.27	79.41	79.55
2.3	79.69	79.83	79.97	80.11	80.25	80.38	80.52	80.65	80.79	80.92
2.4	81.05	81.18	81.31	81.44	81.57	81.69	81.82	81.95	82.08	82.20
2.5	82.32	82.44	82.57	82.69	82.81	82.92	83.04	83.16	83.28	83.39
2.6	83.51	83.62	83.73	83.86	83.96	84.07	84.18	84.29	84.40	84.50
2.7	84.61	84.72	84.82	84.93	85.03	85.13	85.24	85.34	85.44	85.54
2.8	85.64	85.74	85.84	85.94	86.03	86.13	86.23	86.32	86.42	86.51
2.9	86.60	86.69	86.79	86.88	86.97	87.06	87.15	87.24	87.33	87.41

3.0	87.50	87.59	87.67	87.76	87.84	87.93	88.01	88.09	88.17	88.26
3.1	88.34	88.42	88.50	88.58	88.66	88.73	88.81	88.89	88.97	89.04
3.2	89.12	89.19	89.27	89.34	89.42	89.49	89.56	89.63	89.70	89.78
3.3	89.85	89.92	89.99	90.06	90.12	90.19	90.26	90.33	90.39	90.46
3.4	90.53	90.59	90.66	90.72	90.79	90.85	90.91	90.98	91.04	91.10
3.5	91.16	91.22	91.28	91.34	91.40	91.46	91.52	91.58	91.64	91.70
3.6	91.75	91.81	91.87	91.92	91.98	92.03	92.09	92.14	92.20	92.25
3.7	92.31	92.36	92.41	92.46	92.52	92.57	92.62	92.67	92.72	92.77
3.8	92.82	92.87	92.92	92.97	93.02	93.07	93.11	93.16	93.21	93.25
3.9	93.30	93.35	93.39	93.44	93.48	93.53	93.57	93.62	93.66	93.71
X	0.00	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
4	93.75	94.17	94.56	94.92	95.26	95.58	95.88	96.15	96.41	96.65
5	96.88	97.08	97.28	97.46	97.63	97.79	97.94	98.08	98.21	98.33
6	98.44	98.54	98.64	98.73	98.82	98.90	98.97	99.04	99.10	99.16
7	99.22	99.27	99.32	99.37	99.41	99.45	99.48	99.52	99.55	99.58
8	99.61	99.64	99.66	99.68	99.70	99.72	99.74	99.76	99.78	99.79
9	99.8046875									
10	99.90234375									

*The assumption is made that A, the maximum yield possible, is 100%. Under the Mitscherlich-Baule theorem, the first unit of X results in 50% of the maximum possible yield, and each additional unit of X results in increasing the yield by one-half of the difference remaining. The values presented in this table have been determined by means of the formula:

$$A - y = \frac{A}{2^X}.$$

in his book "ABC of Agrobiology" and in several articles[1] in which various diagrams of the universal yield curve have been given to illustrate its use in the interpretation of experimental data.

The universal yield law, as explained in the "ABC of Agrobiology", is a law of diminishing returns in which the first Baule unit of X results in one-half of the maximum possible yield which would result from the X factor if unlimited. The second and each succeeding Baule unit of X increases the yield by one-half of the difference remaining. From this rule or law, the universal yield diagram may be plotted without difficulty for the unit values of X. But when the X values are less than unity or are fractional Baule units, considerable difficulty may be experienced by many in calculating the corresponding y values for the estimated maximum yield value of A.

In an effort to increase the usefulness of the universal yield diagram or curve and to lessen the difficulty of calculating any y value corresponding to any X value for any estimated maximum yield value, A, an universal yield diagram table has been constructed giving the values of y in percentages of A from 0.00 to 100.00% by close intervals for those portions of the universal yield diagram or curve where any change in the value of X results in any appreciable change in the value of y.

This table is based upon the assumption that the maximum possible yield, A, is 100%. The values appearing in the table are, therefore, percentages and any desired curve based upon any estimated maximum possible yield may be readily constructed by multiplying the estimated maximum possible yield, A, by the percentage figure in the table appearing under the proper X values. Or the comparison may be reversed by dividing the observed y values by the estimated maximum yield value and comparing the percentages determined with the percentage figures appearing under the proper X values in the table.—J. G. LILL, *Division of Sugar Plant Investigations, Bureau of Plant Industry, Soils, and Agricultural Engineering, Agricultural Research Administration, U. S Dept. of Agriculture.*

[1]The fertilization of sugar cane. Facts About Sugar, 35, No. 12; 33–37. 1940. Interpretation of Olsen and Shaw's field tests by the Mitscherlich-Baule theorem and the universal yield diagram. Jour. Amer. Soc. Agron., 35:454–459. 1943. Further interpretations of field tests by the universal yield diagram. Jour. Amer. Soc. Agron., 36:386–392. 1944.

BOOK REVIEWS

STATISTICAL METHODS

By George W. Snedecor. Ames, Iowa: Iowa State College Press. Ed. 4. XVI+485 pages, illus. 1946. $4.50.

THIS well-known work has been rather thoroughly revised and much new material has been added. Although there has been an increase in printed matter of about 12%, the new sections and the major rewritten portions are not distributed uniformly throughout the book. There are, however, certain minor revisions and additions that occur in most chapters, such as examples discussed in the text, mathematical formulas and symbols, examples to be solved by the

student, references to the literature, and changes in the titles of certain sections; also, more prominence is given to tests of significance and fiducal limits.

Beyond the changes mentioned above, the following chapters have not been subjected to much alteration, *viz.*, Measurement Data, Short Cuts and Approximations, Large Sample Method, Covariance, Curvilinear Regression, Binomial and Poisson Distributions, and Designs and Analysis of Sampling. The remaining chapters have been either largely or entirely rewritten. Mention will be made of the more important changes only.

The approach to sampling in the opening chapter has been entirely rewritten and two important tables added, (1) 95% Confidence Interval (%) for Binomial Distribution, and (2) Ten Thousand Randomly Assorted Digits. The tables of t and chi-square have been expanded. Two types of linear regression are discussed and the chapter on Correlation has been increased by 67%. Transformation of r to z, or *vice versa*, has been added, including a nomogram from which the values may be secured graphically. The applications of chi-square have been widened to include $2\times2\times2$ and $R\times C$ tables.

The chapter on Analysis of Variance has been enlarged and improved especially by including more of the fundamental equations and underlying theory. For the agronomist and other field experimenters, the analysis of variance when multiple classification is involved, is well handled in relation to random block, split-plot, and Latin square arrangements of plots, and for 2×2, $R\times2$, and $R\times C$ tables. In each case, the treatment is divided according to whether or not interaction is present. In the analysis of variance in regression, much attention is given to the use and calculation of Gauss multipliers when three or more variates are under consideration. In another chapter, individual degrees of freedom are discussed extensively in relation to randomized block experiments and in factorial designs.

A number of sections and figures of the third edition have been omitted, including such section titles as the probable error, two nomograms for determining the number of pairs of observations necessary for significance, the standard error of a forecast, and tests of significance of betas.

In all these alterations, as stated by the author, "the scope of the book has been widened" by placing "greater emphasis on the theoretical conditions in which the various statistical methods have validity and concurrently on the conduct of the experiment so as to incorporate in the data the information desired."

As one examines the earlier editions, it seems, at least to this reviewer, that the present volume is apt to prove somewhat more difficult than the earlier editions for the student who has had little experience with statistical methods. He is liable to become lost in the mass of information. The author has tried to meet this by listing a "short course" on statistics at the beginning of the volume.

The binding and typography have been changed, but the attractive style of the author has not suffered. The additional subjects considered tend to make the present edition a more complete manual.

Professor Snedecor has done an excellent job of revision and the publishers have produced an attractive and well-bound book.—F. Z. HARTZELL.

SOIL AND PLANT ANALYSIS

By C. S. Piper. New York: Interscience Publishers, Inc. XIV+369 pages, illus. 1944. $4.50.

THIS book is divided into two parts, the first giving methods for the physical and chemical analysis of soils, and the second methods for the determination of the inorganic constituents of plants. It is an outgrowth of wide experience by the author of methods used generally in Australia and particularly at the Waite Agricultural Research Institute, University of Adelaide, where he serves as Chemist.

Part I, consisting of 14 chapters, deals successively with the collection and preparation of soil samples, determination of pH and water-soluble salts, mechanical analyses, standard solutions and indicators, calcium carbonate determination, analysis of HCl extract, determination of exchangeable ions, nitrogen, nitrates, ammonia, organic matter, free ferric oxide, and finally separation and analysis of the clay fraction. Part II consists of four chapters which deal with the collection and preparation of plant samples, the ashing of plant material, and the determination of the more common inorganic constituents as well as trace elements. A pertinent list of references is given at the end of each chapter.

An outstanding feature of the book is clearness and preciseness. The main points, as well as the details of the methods given, are fully described and discussed, and further clarified where needed by means of drawings. The ever-present pit-falls in quantitative analysis are well guarded against in the discussions and directions.

Although the book is designed for the special needs as they exist in Australia and New Zealand, there is no doubt but what soil and plant analysts in the United States will find considerable use for this book as a reference work. The reviewer has a feeling that many soil analysts in this country will probably doubt the wisdom of devoting a chapter on the outmoded HCl extraction procedure for soils, and then omitting entirely total analysis by means of sodium carbonate fusion. Also, in this country, many soil chemists would give greater emphasis to the determination of the available or easily soluble portions of plant nutrients, such as phosphorus in particular.—E. TRUOG.

AGRONOMIC AFFAIRS

SUMMER MEETING OF THE NORTHEASTERN SECTION

OFFICERS of the Northeastern Section of the American Society of Agronomy announce that the 1946 summer meeting of the Section will be held at the University of Maryland, College Park, Md., July 22 to 25, inclusive. It is anticipated that the program will

include a trip to Beltsville to inspect the work underway there. Further details on the program may be obtained by addressing Paul R. Miller, Secretary-Treasurer of the Section, at 590 Main Street, Burlington, Vt.

Dormitory facilities of the University of Maryland will be available for both men and women at $1.00 per person per night.

FOOD PACKAGES FOR EUROPE

THE American Society of Agronomy has been requested by Cooperative for American Remittances to Europe, Inc., otherwise known as CARE, to call to the attention of its membership the facilities that have been set up under its auspices to get food packages to Europe.

CARE is described as a nonprofit organization approved by the President's War Relief Control Board, under the direction of Lieut. Gen. William H. Haskell. The food packages provide an average of over 40,000 calories with a net weight of approximately 30 pounds as follows: Solid meat, stews, and hashes; cereal and biscuits; fruit jam and pudding; vegetables; sugar and candy; evaporated milk; preserved butter; cocoa, coffee, and beverage powders; cheese; and miscellaneous items, such a soap, chewing gum, matches, etc.

At the present time CARE packages may be sent to individuals or institutions in Austria, Czechoslovakia, Finland, France, Italy, Netherlands, Norway, Poland, and the U. S. zone of occupation in Germany, with the expectation that Belgium and Greece will soon be included and possibly other nations. Orders are sent by air-express where feasible and are filled overseas from stockpiles already over there. A signed receipt will be obtained when the package is delivered and will be returned to the consignor.

CARE food packages are $15 each and delivery is guaranteed to any designated individual, group, church, or other category of people in the countries named. Where no specific beneficiary is named, CARE's overseas representatives will deliver the food to destitute persons selected by local welfare agencies. By agreement with the countries named above, the food enters the country tax and duty free, recipients are in no way discriminated against with regard to normal rations, and police protection is assured for the food packages.

Food remittance application blanks may be obtained from local banks, churches, lodges, labor unions and other organizations, or CARE, 50 Broad Street, New York 4, N. Y. No agents are authorized to accept payments, all remittances to be made by check with the application.

ALFALFA IMPROVEMENT CONFERENCE

THE NATIONAL ALFALFA IMPROVEMENT CONFERENCE will be held at the Utah Agricultural Experiment Station, Logan, Utah, August 7 to 9, 1946. This will be the first meeting since before the war and it is hoped the different states will be well represented. The

program will include field trips to observe extensive cooperative research work on alfalfa and alfalfa seed production. Studies on cropping systems and irrigation, lygus infestation and control, pollination and seed setting, breeding and improvement, and comparisons of some of the new hybrids and polycrosses will be observed. Discussions will involve alfalfa breeding and improvement techniques, production of foundation seed of improved varieties, and related subjects. All interested workers are invited to attend the conference.

Free housing facilities will be available for both men and women in the Rural Arts Building on the College campus. Perhaps you can include attendance at the Conference in your summer vacation plans. It is requested that those who plan to attend advise David A. Burgoyne, Assistant to the Director, Utah Agricultural Experiment Station, at least two weeks in advance of the Conference, so that arrangements for bed linens, which will be made available at a small cost, can be made.—J. W. CARLSON, *Chairman*.

THE 1946 MEETINGS OF THE AMERICAN SOCIETY OF AGRONOMY AND THE SOIL SCIENCE SOCIETY OF AMERICA

AT THE last meeting of the Executive Committee of the American Society of Agronomy held at Columbus, Ohio, March 1, 1946, Professor H. D. Hughes, President, and G. G. Pohlman, Secretary-Treasurer, were delegated the responsibility of finding a suitable meeting place for the thirty-eighth annual meeting to be held in the fall of 1946. Because of the late date several of the cities contacted were not able to handle our meetings. However we have finally selected the Hotel Fontenelle at Omaha, Nebraska, as our meeting place. The meetings will be held November 19 to 22, inclusive. The first day will be given over to the meeting of the National Joint Committee on Fertilizers and the remaining three days for general and sectional meetings of the American Society of Agronomy and Soil Science Society of America.

Members wishing to present papers should contact program chairmen as soon as possible. The names of the chairmen of the various sections of the Crops and Soils Divisions are listed in the April issue of the JOURNAL (pages 376 and 377).—G. G. POHLMAN, *Secretary*.